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Technical Report 1742-TR

PHASE II OF COMBAT EXCAVATION TESTS OF CRATERING WITH EXPLOSIVES

Task 8F07-10-001-02

7 March 1963

U S Army Engineer Research And Development Laboratories

FORT BELVOIR, VIRGINIA

U. S. ARMY ENGINEER RESEARCH AND DEVELOPMENT LABORATORIES
FORT BELVOIR, VIRGINIA

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THE VIEWS CONTAINED HEREIN REPRESENT ONLY THE VIEWS OF THE PREPARING AGENCY AND HAVE NOT BEEN APPROVED BY THE DEPARTMENT OF THE ARMY.

PREFACE

The Program Guidance Annex for Corps of Engineers Research and Development Program for FY 1961 requires that the following be established under Task 8F07-10-001-02: ". . . design parameters for experimental model components, to include explosive preparation of drill holes as an alternate method, and explosive cratering." A copy of the task card covering the investigation described in this report is contained in Appendix A.

Tests covered by this report were conducted during the period October 1959 through June 1961. All tests were under the direction of E. P. Leland, Senior Engineer, supervised by R. M. Flynn, Chief, Field Defenses Section, Demolitions and Fortifications Branch. All test firings were conducted and controlled by personnel of the Mine Warfare and Barrier Test Unit at the Demolition Test Area, Engineer Proving Ground.

CONTENTS

SUMMARY

This report covers the second phase of testing of cratering for combat excavation with explosive charges placed below ground surface in holes formed by shaped charges. Results of the initial phase of testing were reported in USAERDL Report 1619-TR.

Testing was conducted on Ranges 1 and 3 in the Demolition Test Area, Engineer Proving Ground. Shaped-charge parameters investigated included cone diameter, cone thickness, cone angle, cone material, explosive weight, explosive-loaded-height above cone apex, and standoff. Experimental cratering charges included long and short charges, and charges of different weights and cross-section configuration. Measurements were recorded of the dimensions of the shaped-charge holes and the cleaned craters.

Experiments included 189 shaped-charge tests and 100 cratering tests.

The report concludes:

a. The incorporation of linear-shaped charge capability in cratering-charge configuration has negligible effect upon crater shape and volume.

b. Due to waste of energy near soil surface, the cratering efficiency of long cratering charges (i. e., charges whose length is greater than one-half the bore-hole depth) is inferior to that of shorter charges.

c. Small shaped and cratering charges in a two-stage system, as described within the text and weighing less than 1 pound gross, can be effectively used to assist in excavating a foxhole.

d. Paste explosive (modified Composition C-4) is applicable for expedient shaped charges because of its ease of loading; however, its performance is inferior to that of hand-loaded Composition C-4.

e. The scope of the tests performed provides the basis for future investigation of 60- and 90-degree shaped charge liners and cratering charge characteristics, configuration, and method of placement.

PHASE II OF COMBAT EXCAVATION TESTS OF CRATERING WITH EXPLOSIVES

I. INTRODUCTION

1. Subject. This report covers the second phase of a test program to determine feasibility of cratering for combat excavations with explosive charges placed below ground surface in holes formed by shaped charges.

2. Background and Previous Investigation. Initial work on this subject was conducted during 1958-59. The report covering the work[1] concluded that:

a. A 2-pound shaped charge used in conjunction with a $1\frac{1}{2}$-pound cratering charge can form a foxhole 4 feet deep by 3 to 5 feet wide in most soils.

b. The indicated requirements for the 2-pound shaped charge are a 70-degree, 1/8-inch-thick, $3\frac{1}{2}$-inch-diameter, copper conical liner and 2 pounds of explosive.

c. The indicated configuration of the $1\frac{1}{2}$-pound cratering charge is a regular cylinder, 2 inches in diameter and 9 inches in length.

d. The gross weight of the two charges, including packaging, is about 4 pounds.

e. Subsequent investigation should include more testing of shaped-charge standoff, cone angle, and explosive loaded height above cone apex.

f. The use of long, small-diameter cratering charges in preference to the short, larger-diameter cratering charge warrants further investigation since the longer charge appears to give better foxhole configuration.

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1. E. P. Leland, Combat Excavation by Cratering with Explosives, Report 1619-TR (Fort Belvoir, Va.: U. S. Army Engineer Research and Development Laboratories, 18 March 1960).

II. INVESTIGATION

3. Description of Charges. Shaped charges for making the initial holes in the ground and cratering charges for detonation in these holes were used in this investigation.

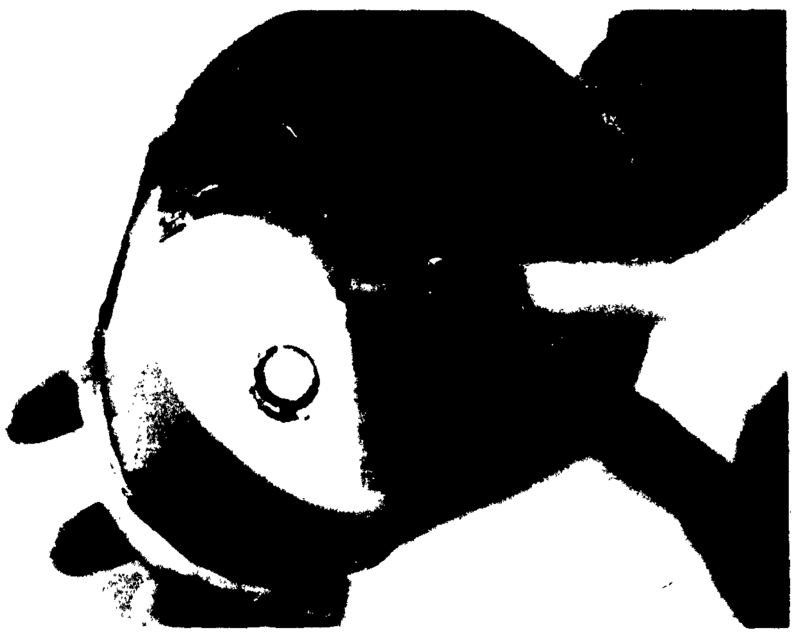
a. Shaped Charges. The term "shaped charge" signifies an explosive charge in which the explosive is shaped in such a manner as to produce a desired effect not otherwise available. The explosive is shaped about a cavity in the charge. The effect produced by charges with cavities is known as the "Munroe effect" after Charles E. Munroe, who announced in 1888 that he had discovered the effect with hollowed charges. The cavity may be conical, hemispherical, bell shaped, and the like. The addition to the cavity of a thin liner of material such as steel, copper, aluminum, or glass results in an increase in this effect. The existence of the lined cavity causes a concentration of the explosive forces when the charge is detonated, resulting in the formation of an extremely high velocity jet. This jet, which moves in a direction away from the cavity, is capable of perforating or penetrating deeply into many materials, including concrete and metals. The usual configuration of a shaped charge is cylindrical, although the explosive may be tapered at the end of the charge away from the cavity.

Shaped charges included in these tests consisted of experimental charges and two commercially available charges.

The experimental charges were of uneven quality. Copper conical liners were formed as described and shown in paragraph 3a of Report 1619-TR, except for nine quality, spun-formed liners. Aluminum cones were machined from 6061 bar stock and subsequently annealed. Lead and eutectic lead cones were cast. Eutectic lead-antimony cones contained 88.8 percent lead and 11.2 percent antimony. Eutectic lead-tin cones contained 61.9 percent lead and 38.1 percent tin. The experimental charges were loaded with either Composition C-4 or a paste explosive as shown in Fig. 1. The charges were loaded to a specified point above the cone apex and leveled off. A cross-sectional view of a hand-tamped experimental shaped charge is shown in Fig. 2. In some instances, a 15-gram PETN booster was incorporated at the top center above the cone apex.

The paste explosive used in these tests is composed principally of RDX. It is formed by modifying Composition C-4 by addition of DNT (dinitrotoluene) and MNT (mononitrotoluene) oils and Shell 40 Thinner. The composition of paste explosive is as follows:

E4179



H1073

Fig. 1. Hand tamping of Composition C-4 (top) and paste explosive (bottom) into experimental shaped charge.

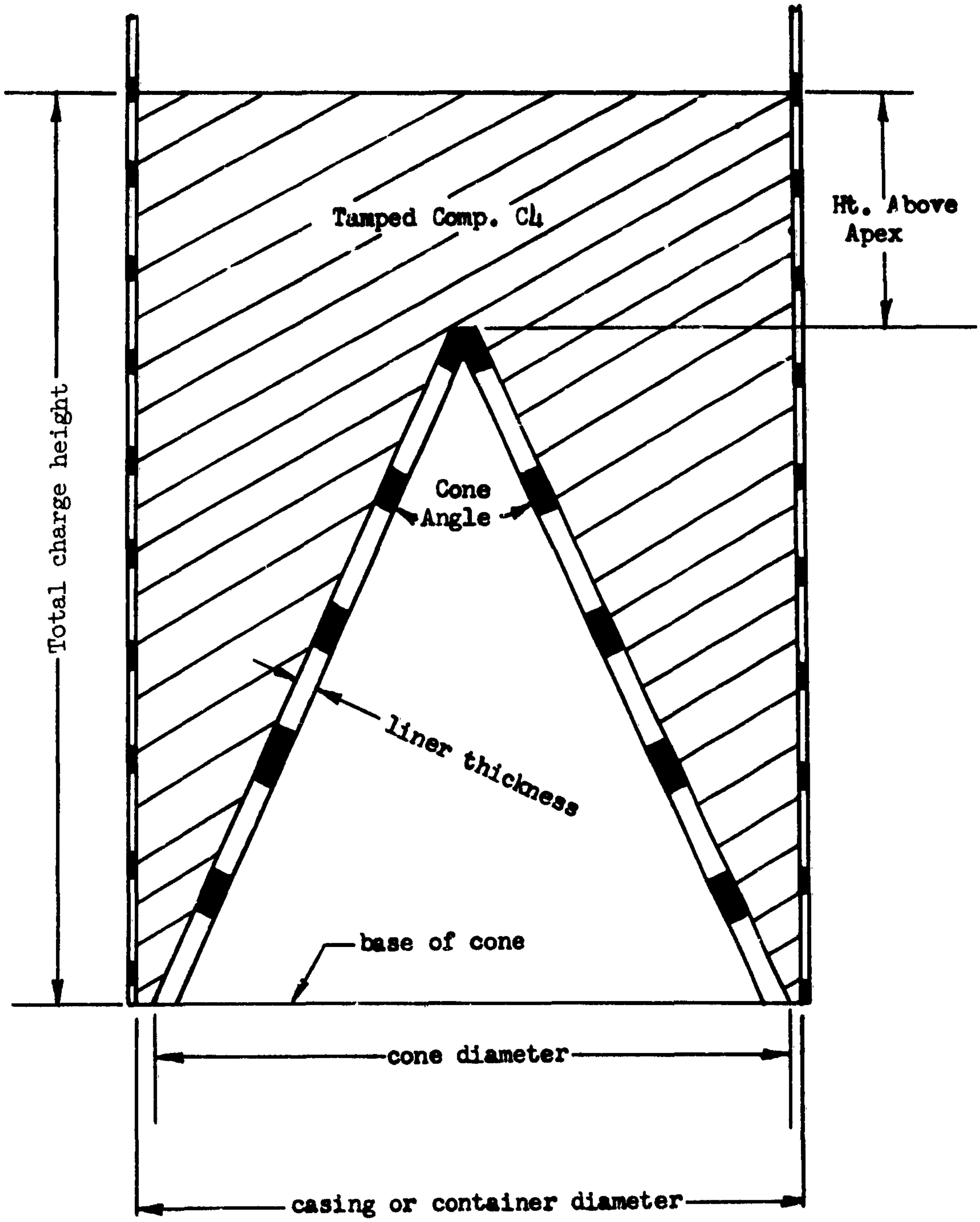


Fig. 2. Cross section of hand-tamped experimental shaped charges.

Ingredient	Percentage of Paste Explosive
RDX	76.44
DNT	4.89
MNT	3.26
Shell 40 Thinner	7.85
C-4 Plasticizer (Polyisobutylene, 1.74 percent; Motor Oil, 1.36 percent; and di-(2-ethylhexyl) sebacate, 4.46 percent)	7.56

The pasty consistency of the paste explosive made it suitable for loading the improvised charges. The paste explosive was easier to load than was Composition C-4. The 15-gram boosters were inserted into the paste explosive just prior to detonation since the oils in the explosive tended to dissolve the booster over a period of a few hours. The paste explosive has a detonation rate of approximately 24,000 feet per second and is considerably less sensitive and somewhat less powerful than Composition C-4.

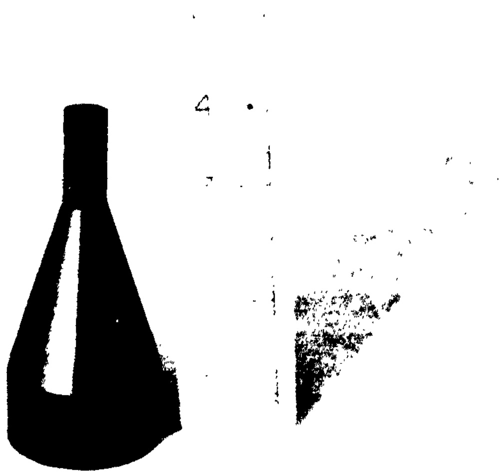
The two commercial shaped charges were obtained from E. I. duPont deNemours and Company. They were the 34A Jet Perforator and the Jet Tapper which are used for perforating oil well casings and tapping in open hearth furnaces, respectively. The 34A Jet Perforator (Fig. 3) is a 2-inch-diameter, plastic-cased charge containing 34 grams of RDX and a 60-degree, 1/32-inch-thick copper liner of 1-9/16-inch diameter. The Jet Tapper (Fig. 4) is a 2-inch-diameter, plastic-cased charge containing 63.5 grams of RDX and an 80-degree, 1/32-inch-thick copper liner of 1-3/4-inch diameter.

b. Cratering Charges. The cratering charges used in these tests were hand-tamped loaded with Composition C-4. Three methods of packaging the cratering charges were employed: (1) Paper tubes (Fig. 5) for small diameter (7/8 inch or less), lightweight (1/2 pound or less) charges, (2) aluminum tubing for long (over 24 inches) charges, and (3) 21-gage sheet metal for the non-cylindrical charges (Fig. 6). Charges ranging from 0.15 pound to 2.0 pounds were packaged in containers with diameters varying from 1/2 to $1\frac{1}{4}$ inch and lengths varying from 8-5/8 to 37 inches. The non-cylindrical charges (Figs. 6 and 7) were linear shaped. Tests were made of four designs: Type A, circular cross section for evaluation comparison; Type B, vee-notched rectangular section; Type C, eight-pointed star; and Type D, Maltese Cross. The purpose of these designs was to determine whether the linear shaped charge configuration would result in an increase in cratering efficiency over a cylindrical configuration charge. The four designs include small

J2674

J2672

Fig. 3. Jet Perforator No. 34A shaped charge.



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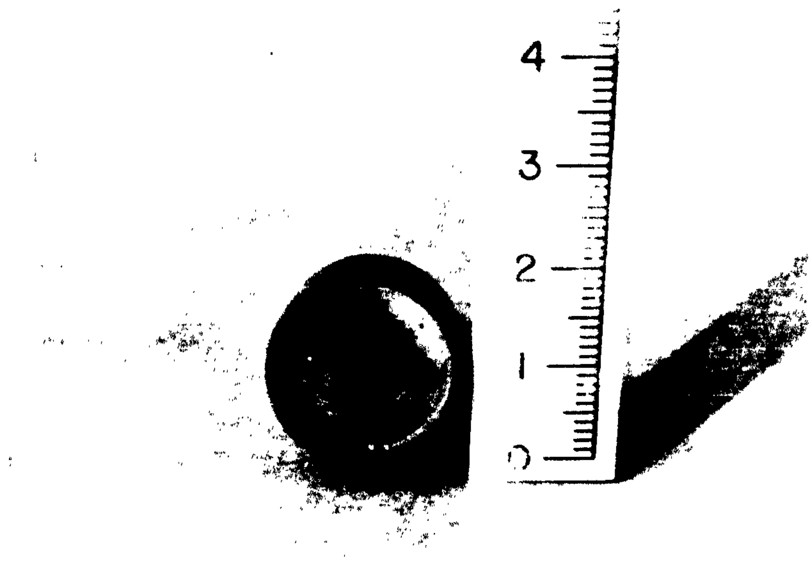

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Fig. 4. Jet Tapper shaped charge.

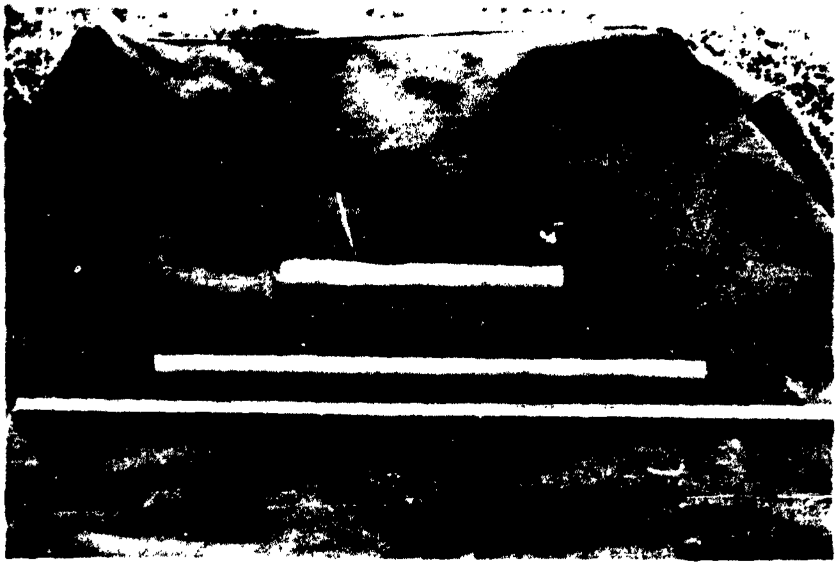

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Fig. 5. Paper-cased, lightweight cratering charges.

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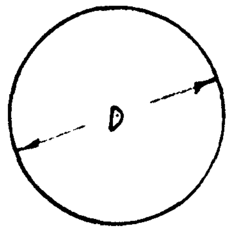
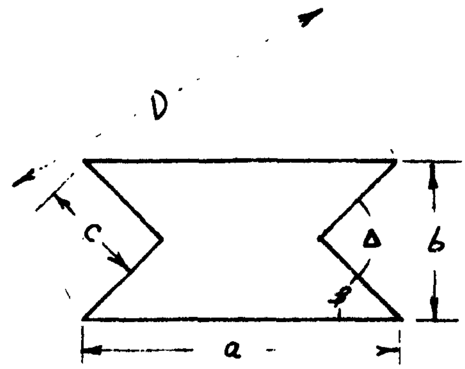
Fig. 6. Non-cylindrical cratering charges and cylindrical comparison charge.



Type A



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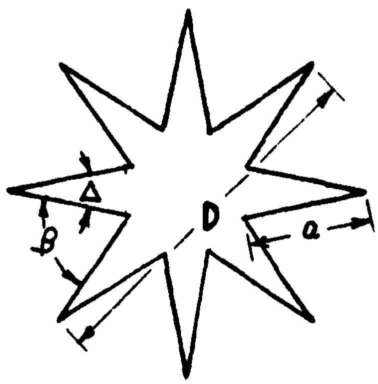
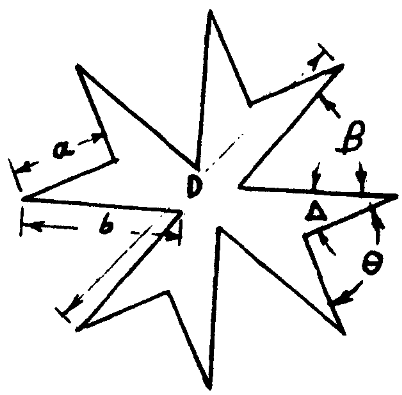


Type C



Type D

Type	D	a	b	c	Angle β	Angle Δ	Angle θ
A	1.25	-	-	-	-	-	-
B	2.01	1.80	0.90	0.64	45°	90°	-
C	2.06	0.69	-	-	70°	25°	-
D	2.13	0.57	0.90	-	53.5°	26.75°	90°

Fig. 7. Cratering charge configuration.

and large linear charge angles plus small and large angle sides (Fig. 7) and were considered to cover an adequate range of shapes for proper evaluation.

4. Test Procedure and Results. Testing was performed on Ranges 1 and 3 at the Demolition Test Area, Engineer Proving Ground. Both soils are a lean sandy clay (type CL) with a density of 105 pounds per cubic foot to the 12-inch depth and 113 pounds per cubic foot from 1- to 4-foot depth (Appendix B).

a. Shaped Charges. After the desired standoff (measured in calibers, i. e., height above ground divided by cone diameter) was selected, the shaped charge was adjusted for this standoff by means of three steel or wooden dowels (Fig. 8). The J-2 special electric blasting cap was used as the initiator for all shaped charges. The experimental charges without boosters were primed with two caps. An unassembled experimental shaped charge including the paste explosive, booster, and blasting cap is shown in Fig. 9. The method of priming an experimental shaped charge loaded with Composition C-4 is shown in Fig. 10. The typical firing setup of the Jet Tapper is shown in Fig. 11.

After the charge was fired, each hole was measured for clean dimensions. The measurements were made with measuring tapes and with circular metal disks. The disks were lowered into the holes to the maximum depth which the various diameters of the disks would permit. In addition, a small-diameter rod was pushed into the bottom of the hole through the sloughed-in soil to measure total depth.

The experimental-charge tests consisted of firing charges incorporating variations in explosive type, cone angle, cone thickness, cone material, cone diameter, standoff, and explosive-loaded-height above cone apex. A summary of all shaped-charge firings is contained in Table I. The table gives data on the charge itself plus dimensions of the resulting hole. The last four columns refer to hole dimensions. The usable depth is the depth to the sloughed-in spoil, providing the diameter is 1 inch minimum for the experimental charges and 1/2 inch minimum for the commercial stock charges. The usable diameter is the minimum diameter occurring at or above the usable depth. The total depth is the depth to the bottom of the hole through the sloughed-in spoil. The surface diameter is the maximum diameter of the disturbed soil. The maximum diameter usually occurs for a depth of 1 inch or less. The diameters at depths of about 2 inches are usually less than one-third the surface diameters. Figure 12 illustrates the dimensioning procedure.

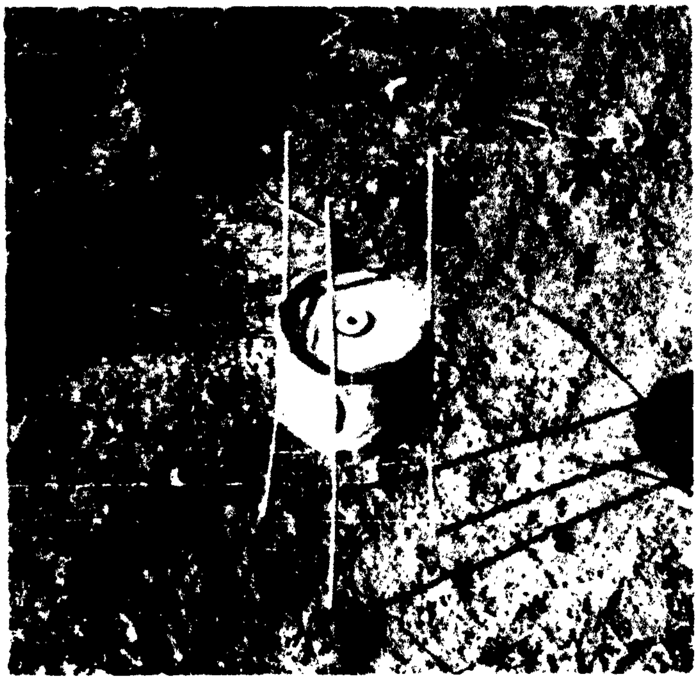


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Fig. 8. Experimental shaped charge in firing position.

H1070

Fig. 9. Experimental shaped charge prior to assembly.

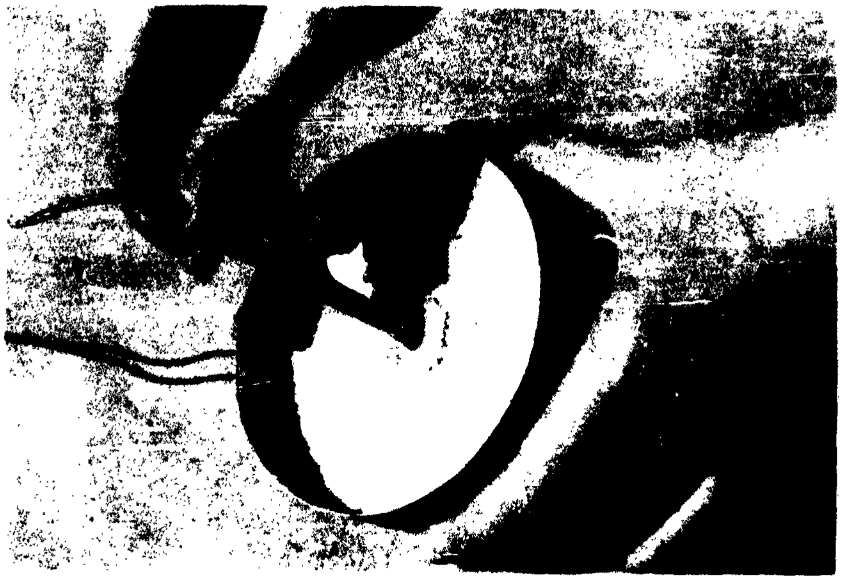

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Fig. 10. Priming shaped charge with J-2 blasting cap.

G6637

Fig. 11. Jet Tapper shaped charge in firing position.

Table I. Shaped-Charge Firings

	Charge Parameters					Results				
Charge	Charge Type[(a)]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[(b)]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
1	90C	4	4-1/2	1.92	3/4	1.00	28	46	2	43
2	"	"	"	1.89	"	1.00	33	47	3-1/2	36
3	"	"	"	1.98	"	1.81	25	50	4	40
4	"	"	"	2.22	1	1.00	24	45	3-1/2	36
5	"	"	"	2.21	"	1.00	25	42	3	38
6	"	"	"	2.26	"	1.25	24	48	4-1/2	42
7	"	"	"	2.14	"	1.25	30	53	4	39
8	"	"	"	2.36	1-1/4	1.00	14	44	3-1/2	39
9	"	"	"	2.49	"	1.00	26	45	5	36
10	"	"	"	2.52	"	1.25	31	47	4	39
11	"	"	"	2.38	"	1.25	32	47	3-1/2	39
12	"	"	"	2.55	1-1/2	1.00	29	46	3-1/2	29
13	"	"	"	2.65	"	1.00	33	49	4	34
14	"	"	"	2.57	"	1.25	22	48	4	43
15	"	"	"	2.54	"	1.25	22	48	4	43
16	70C	3-15/16	4-1/4	1.95	3/4	1.00	25	33	4	24
17	"	"	"	1.87	"	1.00	28	46	3	43
18	"	"	"	1.86	"	2.00	25	51	3	39
19	"	"	"	2.05	1	1.28	31	46	2	46
20	"	"	"	2.05	"	1.28	23	35	4	24
21	"	"	"	2.01	"	1.00	23	38	2-1/2	29
22	"	"	"	2.08	"	2.00	23	41	3	30
23	"	"	"	2.30	1-1/4	1.28	28	51	3	40
24	"	"	"	2.26	"	1.72	25	36	3	22
25	"	"	"	2.26	"	1.00	30	45	3	40

Table I (cont'd)

	Charge Parameters					Results				
Charge	Charge Type[a]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[b]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
26	70C	3-15/16	4-1/4	2.28	1-1/4	2.00	29	41	5	17
27	"	"	"	2.41	1-1/2	1.72	27	43	2-1/2	37
28	"	"	"	2.41	"	1.28	10	36	2-1/2	33
29	"	"	"	2.42	"	1.00	28	48	2-1/2	23
30	"	"	"	2.43	"	2.00	28	35	2	30
31	70C	3-5/8	4-1/16	2.00	1	2.00	19	47	4	42
32	"	"	"	2.00	"	3.00	20	35	4	26
33	"	"	"	2.01	"	4.00	16	48	4	34
34	"	"	"	1.97	"	2.50	19	43	4	35
35	"	"	"	2.12	1-1/4	2.00	28	42	5	28
36	"	"	"	2.13	"	3.00	19	49	4	33
37	"	"	"	2.11	"	4.00	18	44	4	32
38	"	"	"	2.13	"	2.50	17	35	3	22
39	"	"	"	2.38	1-1/2	2.00	22	33	6	12
40	"	"	"	2.37	"	3.00	18	37	3	21
41	"	"	"	2.33	"	4.00	20	46	3	15
42	"	"	"	2.35	"	2.50	21	49	4	41
43	"	"	"	2.36	"	1.00	24	35	3	24
44	"	"	"	2.53	1-3/4	2.00	16	46	4	29
45	"	"	"	2.51	"	3.00	21	34	6	8
46	"	"	"	2.48	"	4.00	20	35	5	18
47	"	"	"	2.50	"	2.50	23	30	4	18
48	"	"	"	2.54	"	1.00	31	31	5	16
49	90C	3-11/16	4-1/16	1.62	1	2.00	16	39	2-1/2	28
50	"	"	"	1.61	"	3.00	24	42	6	9

Table I (cont'd)

Charge Parameters						Results					
Charge	Charge Type[(a)]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[(b)]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
51	90C	3-11/16	4-1/16	1.70	1	4.00	24	44	3	21
52	"	"	"	1.67	"	2.50	24	45	2	32
53	"	"	"	1.83	1-1/4	2.00	22	41	2	29
54	"	"	"	1.83	"	3.00	26	46	2-1/2	32
55	"	"	"	1.82	"	4.00	22	37	3	24
56	"	"	"	1.81	"	2.50	24	36	2-1/2	27
57	"	"	"	1.98	1-1/2	2.00	24	43	3	32
58	"	"	"	2.02	"	3.00	26	38	3-1/2	18
59	"	"	"	1.99	"	4.00	26	37	2-1/2	31
60	"	"	"	1.96	"	2.50	24	44	2-1/2	33
61	"	"	"	2.04	"	1.00	32	25	3	20
62	"	"	"	2.16	1-3/4	2.00	24	46	3	24-1/2
63	"	"	"	2.26	"	3.00	24	46	4	19
64	"	"	"	2.23	"	4.00	29	41	3	26
65	"	"	"	2.17	"	2.50	26	45	2-1/2	23
66	"	"	"	2.27	"	1.00	30	35	4	24
67	70A	4	4	2.20	Varies	2.00	34	31	6	14
68	"	"	"	"	"	3.00	30	29	4	20
69	"	"	"	"	"	4.00	32	28	3	19
70	"	"	"	"	"	5.00	24	31	6	10
71	"	"	"	"	"	5.50	5-1/2	31	5	21
72	"	"	"	"	"	6.00	29	40	4	27
73	"	"	"	"	"	6.50	31	41	3-1/2	21
74	"	"	"	"	"	7.00	25	34	5	27
75	"	"	"	"	"	7.50	30	38-1/2	4	33

Table I (cont'd)

	Charge Parameters					Results				
Charge	Charge Type[a]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[b]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
76	70A	4	4	2.20	Varies	7.50	32	41	4	36
77	"	"	"	"	"	7.50	30	38	4	33
78	"	"	"	"	"	8.00	30	35	4	29
79	60LA	3-1/2	3-1/2	1.76	1-1/2	3.00	26	23	2	19
80	"	"	"	1.78	"	4.00	32	29	2	11
81	"	"	"	1.81	"	5.00	31	47	1-1/2	25
82	"	"	"	1.77	"	6.00	28	23	1	12
83	"	"	"	1.74	"	7.00	27	26	2	19
84	60LT	"	"	1.84	"	3.00	30	26	3	17
85	"	"	"	1.82	"	4.00	34	23	1-1/2	20
86	"	"	"	1.87	"	5.00	28	32	1-1/2	28
87	"	"	"	1.44	"	6.00	29	35	1-1/2	34
88	"	"	"	1.85	"	7.00	26	16	6	14
89	60L	3-1/2	3-1/2	1.65	1-1/2	3.00	25	23	3	8
90	"	"	"	1.74	"	4.00	26	23	2	13
91	"	"	"	1.68	"	5.00	25	19	2	9
92	"	"	"	1.70	"	6.00	22	18	1	15
93	"	"	"	1.66	"	7.00	25	33	1	20
94	70Ct	4-1/16	4-1/8	1.84	3/4	2.00	28	38	3-1/2	33
95	"	"	"	1.81	"	2.50	26	32	2-1/2	22
96	"	"	"	1.82	"	3.00	24	49	4-1/2	34
97	"	"	"	2.01	15/16	2.00	27	47	6	31
98	"	"	"	1.97	"	2.50	24	44	3	29
99	"	"	"	1.99	"	3.00	24	40	4	21
100	"	"	"	1.79	3/4[c]	2.00	25	32	10	14

Table I (cont'd)

Charge Parameters						Results				
Charge	Charge Type[a]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[b]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
101	70Ct	4-1/16	4-1/8	1.84	3/4[c]	2.50	20	43	5-1/2	17
102	"	"	"	1.81	"	3.00	28	38	5-1/2	15
103	"	"	"	1.89	15/16[c]	2.50	25	41	5	17
104	"	"	"	1.92	"	3.00	25	40	5	24
105	"	"	"	1.86	7/8[c]	2.50	25	35	3-1/2	19
106	70Ct1	4-1/8	4-1/8	1.76	5/8	2.00	25	60	3-1/2	37
107	"	"	"	1.74	"	2.50	24	61	4	39
108	"	"	"	1.72	"	3.00	24	57	4	30
109	"	"	"	1.97	15/16	2.00	23	49	5	25
110	"	"	"	1.92	"	2.50	25	58	5	42
111	"	"	"	1.96	"	3.00	21	60	4-1/2	50
112	"	"	"	1.79	3/4[c]	2.00	24	45	5	30
113	"	"	"	1.77	"	2.50	24	53	5	32
114	"	"	"	1.76	"	3.00	22	59	4	40
115	"	"	"	1.89	15/16[c]	2.50	22	60	5	34
116	"	"	"	1.90	"	3.00	27	45	5-1/2	18
117	"	"	"	1.83	7/8[c]	2.50	21	43	3	23
118	70Ct2	4-1/8	4-1/8	1.71	5/8	2.00	21	54	3	44
119	"	"	"	1.68	"	2.50	22	50	2-1/2	42
120	"	"	"	1.65	"	3.00	24	55	3-1/2	40
121	"	"	"	1.89	15/16	2.00	27	61	3	45
122	"	"	"	1.94	"	2.50	23	62	4	35
123	"	"	"	1.91	"	3.00	21	45	4	32
124	"	"	"	1.71	5/8[c]	2.00	21	57	3	38
125	"	"	"	1.68	"	2.50	24	57	3	38

Table I (cont'd)

	Charge Parameters					Results				
Charge	Charge Type[a]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[b]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
126	70Ct2	4-1/8	4-1/8	1.68	5/8[c]	3.00	20	47	2-1/2	37
127	"	"	"	1.86	7/8[c]	2.00	12	46	3-1/2	28
128	"	"	"	1.89	"	2.50	15	46	3-1/2	26
129	"	"	"	1.90	"	2.50	21	54	2	45
130	70Ct3	4-1/4	4-1/4	1.79	5/8	2.00	24	45	3	29
131	"	"	"	1.80	"	2.50	21	46	3	22
132	"	"	"	1.79	"	3.00	22	45	5	14
133	"	"	"	1.97	7/8	2.00	23	60	2-1/2	44
134	"	"	"	2.02	"	2.50	19	60	3	24
135	"	"	"	1.99	"	3.00	22	48	3	19
136	"	"	"	1.76	5/8[c]	2.00	20	42	2-1/2	24
137	"	"	"	1.77	"	2.50	19	39	3	25
138	"	"	"	1.78	"	3.00	20	38	2-1/2	23
139	"	"	"	1.91	7/8[c]	2.00	21	42	2	36
140	"	"	"	1.93	"	2.50	20	43	2-1/2	29
141	"	"	"	1.92	"	2.50	21	40	3	23
142	80Ct3	3-3/4	3-3/4	1.29	3/4	2.00	22	43	2-1/2	25
143	"	"	"	1.26	"	2.50	20	38	2-1/2	34
144	"	"	"	1.27	"	3.33	20	45	2	30
145	"	"	"	1.41	1	2.00	18	45	3	31
146	"	"	"	1.39	"	2.50	18	42	2	35
147	"	"	"	1.41	"	3.33	21	41	2-1/2	35
148	"	"	"	1.58	1-1/4	2.00	23	50	4	24
149	"	"	"	1.53	"	2.50	19	49	3	33
150	"	"	"	1.55	"	3.33	18	48	2-1/2	42

Table I (cont'd)

	Charge Parameters					Results				
Charge	Charge Type(a)	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)(b)	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
151	80Ct3	3-3/4	3-3/4	1.35	7/8(c)	2.50	20	36	2-1/2	22
152	60Cq	3-1/2	3-1/2	1.29	7/8	2.00	20	48	2	15
153	"	"	"	1.30	"	2.00	18	60	2	43
154	"	"	"	1.37	1	2.00	24	55	2-1/2	44
155	"	"	"	1.39	"	2.00	21	50	4	41
156	"	"	"	1.44	1-1/8	2.00	24	44	4-1/2	36
157	"	"	"	1.43	"	2.00	20	52	1-1/2	46
158	"	"	"	1.49	1-1/4	2.00	22	46	2-3/4	34
159	"	"	"	1.50	"	2.00	21	55	4	39
160	"	"	"	1.58	1-3/8	2.00	22	52	5	23
161	Tapper	1-3/4	2	0.14	--	2.00	14	27	1	20
162	"	"	"	"	--	2.29	12	24	13/16	23
163	"	"	"	"	--	2.50	11	21	1-1/8	17
164	"	"	"	"	--	2.00	12	18	1-1/4	17
165	"	"	"	"	--	2.29	13	25	7/8	23
166	"	"	"	"	--	2.50	12	23	7/8	21
167	"	"	"	"	--	3.00	11	23	7/8	20
168	"	"	"	"	--	2.00	11	20	1	16
169	"	"	"	"	--	2.29	12	25	1-1/4	22
170	"	"	"	"	--	2.50	12	22	7/8	20
171	"	"	"	"	--	3.00	8	25	7/8	20
172	"	"	"	"	--	2.29	12	24	1-1/4	22
173	"	"	"	"	--	2.29	9	23	1-1/4	22
174	"	"	"	"	--	2.29	8	27	1-1/4	19
175	"	"	"	"	--	2.29	8	25	1-1/4	21

Table I (cont'd)

	Charge Parameters					Results				
Charge	Charge Type[a]	Cone Diameter (in.)	Case Diameter (in.)	Expl. Weight (lb)[b]	Loaded Height above Apex (in.)	Stand-off (cal.)	Surface Diameter (in.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
176	Tapper	1-3/4	2	0.14	--	2.29	6	20	7/8	19
177	"	"	"	"	--	2.29	7	20	7/8	19
178	"	"	"	"	--	2.29	9	20	1-1/8	13
179	"	"	"	"	--	2.29	6	25	7/8	19
180	Perforator[d]	1-9/16	2	0.075	--	2.57	7	18	1/2	17
181	"	"	"	"	--	2.57	7	14	1/2	13-1/2
182	"	"	"	"	--	2.57	10	12	1/2	11
183	"	"	"	"	--	2.57	10	15	1/2	13
184	"	"	"	"	--	2.57	8	13	1/2	12
185	"	"	"	"	--	2.57	9	16	1/2	14
186	"	"	"	"	--	2.57	10	14	1/2	8
187	"	"	"	"	--	2.57	9	18	1/2	17
188	"	"	"	"	--	2.57	9	18	1/2	10
189	"	"	"	"	--	2.57	9	18	1/2	17

(a) The figures 60, 70, 80, and 90 signify the cone apex angle in degrees. The letter refers to the cone material: C for copper, 1/8 inch thick; A for aluminum, 1/8 inch thick; L for lead, 1/8 inch thick; LA for eutectic lead-antimony, 1/8 inch thick; LT for eutectic lead-tin, 1/8 inch thick. These cone thicknesses apply except when suffix "t" occurs. The suffixes are as follows: t - 1/16 inch thick; t1 - 3/32 inch thick; t2 - 1/8 inch thick, t3 - 3/16 inch thick. The suffix "q" designates a spun quality cone. See paragraph 3a for description of Tapper and Perforator charges and aluminum and lead cones.

(b) Charges 67-160 include a 15-gram PETN booster centered at top above cone apex.

(c) Charges loaded with paste explosive instead of Composition C-4.

(d) Charges 180-184 included a 1/16-inch-thick cardboard disk placed just below the cone cavity. Charges 185-189 did not include the disk.

Table I describes the charges as expressed in terms of cone angle and material, cone diameter, container diameter, explosive weight, explosive-loaded-height above cone apex, and standoff.

The number of the charges is not a chronological listing of firings but rather a grouping of the charges by types. A typical profile of the resulting satisfactory hole from a shaped-charge firing is shown in Fig. 12. The holes formed by the hand-tamped shaped charges were generally irregular; e. g., the holes were usually elliptical rather than circular. Typical surface rupture as formed by the experimental charges and the Jet Tapper are shown in Fig. 13.

Charges 180-189 were designed to determine whether a thin, low-density plate (cardboard) placed across the base of the cone would markedly affect shaped-charge performance. The purpose of these firings was to determine whether a lightweight cylindrical container could be used to provide standoff as well as packaging for the charge.

b. Cratering Charges. One hundred cratering charges were employed. The charges were placed within bore holes (pilot holes) to desired depths. Many of the shaped-charge holes were suitable for use as pilot holes for the cratering charges. To provide replacements for holes which were not usable, two types of drills were employed. One of the drills (Fig. 14) was a hand-type drill capable of drilling holes of 2-inch diameter. The other drill (Fig. 15) was an electric type employing a 3/4-inch-diameter ship-auger bit (Fig. 16). Charges were placed at different specific depths for full evaluation. In some instances, the charges were tamped by filling the bore hole above the charge with compacted soil. One J-2 special electric blasting cap, embedded within the upper end of the cratering charge, was used as the initiator (Fig. 17).

After the cratering charge was detonated, each hole was cleaned of all loosened material and dimensions of the cleaned hole were measured. A summary of all cratering-charge firings is contained in Table II. The table provides the following descriptive data for each charge: weight, diameter, length, and depth below ground surface to center of gravity. The cleaned crater dimensions are recorded as follows: crater diameter at the ground surface, maximum crater depth, and diameter of bottom bowl. Whether or not a partial camouflet was formed is also noted.

A convenient method of evaluating the crater as a one-man foxhole is shown in the vulnerability-angle column. The

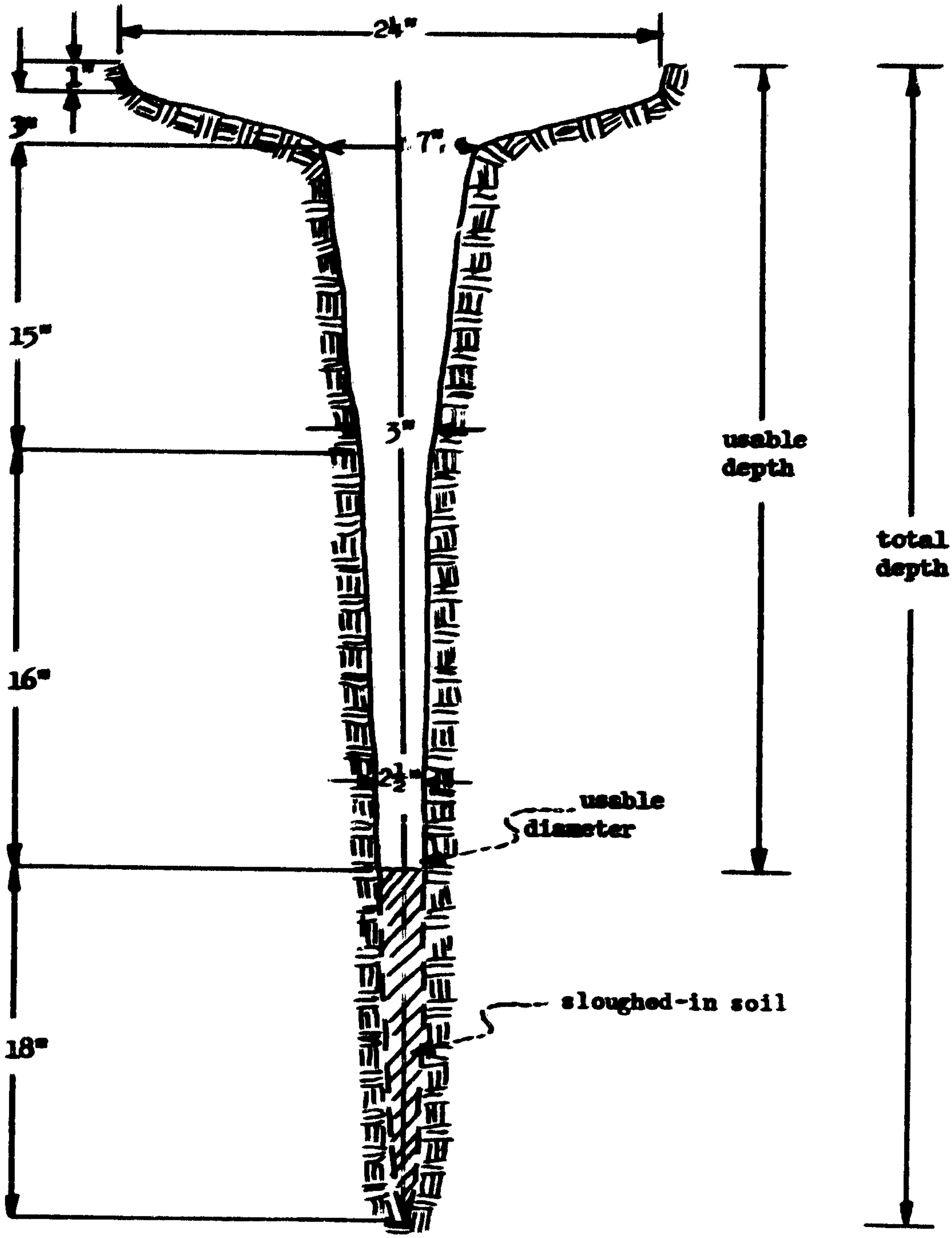
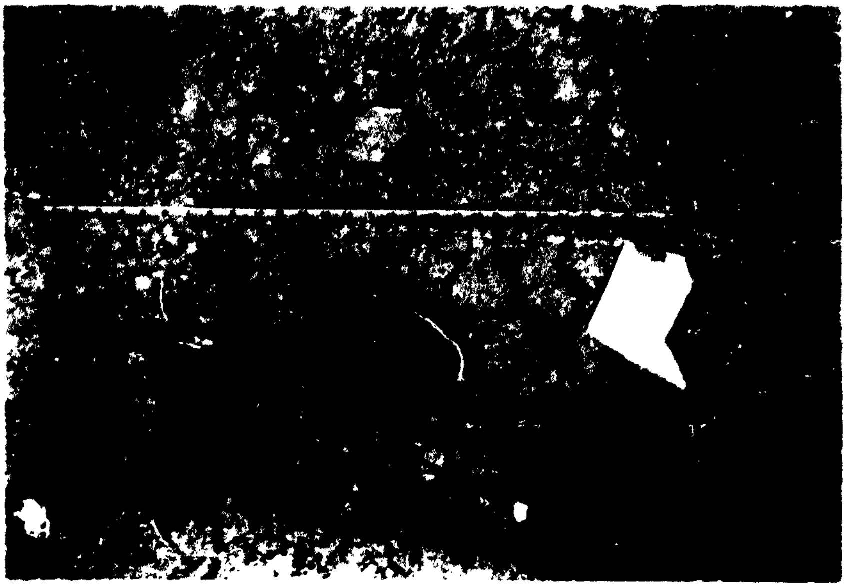


Fig. 12. Profile of typical shaped-charge hole.



G6860

G6636

Fig. 13. Holes formed by typical experimental shaped charge (top) and by Jet Tapper (bottom).

H4030

Fig. 14. Drilling bore holes with hand auger.

G6565

Fig. 15. Augering bore holes with electric drill.

G6566

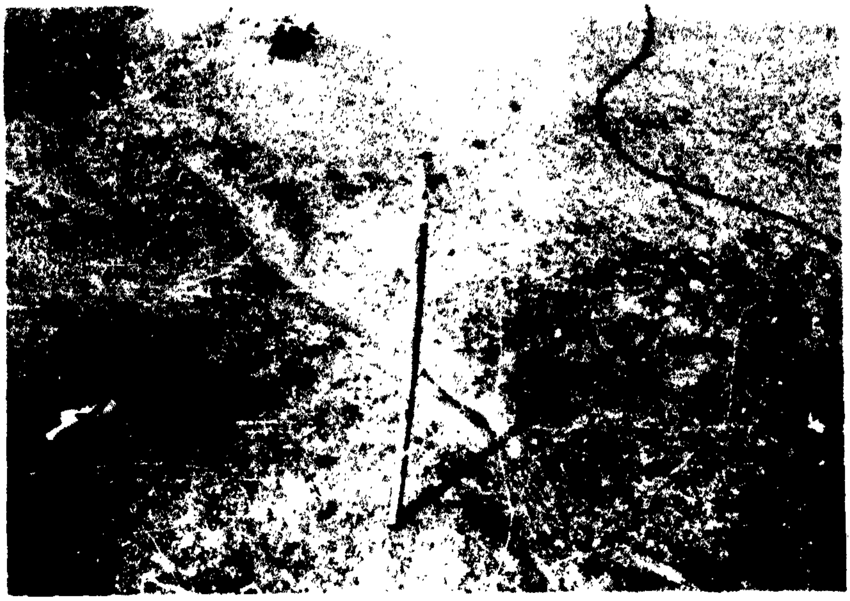
Fig. 16. Ship-auger bit.

vulnerability angle is the vertical angle between a point 18 inches above the bottom of the crater to opposite points at the top edges of the crater (Fig. 18). The average man can crouch to a height of about 36 inches. The average radiation vulnerability height was selected to be one-half the total height or 18 inches. In some instances, because of the narrowness of the bottom bowl, the vulnerability angle gives a false reading when the man is unable to crouch.

The typical surface rupture caused by a lightweight cratering charge and the resulting cleaned crater are shown in Figs. 19 and 20, respectively.

The firings of the lightweight, small-diameter charges (1-46) were designed to determine the optimum charge configuration to be employed with a small shaped charge such as the Jet Tapper. The tests with the long charges (47-64) were designed to determine whether this configuration is suitable for cratering.

As part of the above testing, the small charges were also used in multiple. These were designed to determine whether a better crater could be formed by this method in comparison with a larger single charge. These were charges 28-34C, 36-36D, and 42-42C.



G6562

H4034

Fig. 17. Armed small-diameter cratering charge (top) and vee-notched cratering charge (bottom).

Table II. Cratering-Charge Firings

	Charge Parameters				Results				
Charge	Charge Weight (lb)	Charge Diameter (in.)	Charge Length (in.)	Depth to Center of Gravity of Charge (in.)	Crater Diameter (in.)	Crater Depth (in.)	Bowl Diameter (in.)	Partial Camouflet (?)	Vulnerability Angle (deg.)
1	0.25	5/8	16-5/8	10-3/4	38	23	12	No	150
2	"	"	"	13-3/4(a)	32	25	9-1/2	No	133
3	"	"	"	8-3/4(a)	32	22	5-1/2	No	152
4	0.33	"	21-7/8	11	40	25	18	No	141
5	"	"	"	9(a)	36	23	18	No	149
6	"	"	"	13(a)	38	27	12	No	129
7	0.25	3/4	11-7/8	16	37	24	15	No	144
8	"	"	"	14(a)	34	22	16	No	153
9	"	"	"	18(a)	38	27	11	No	129
10	0.33	"	15-7/8	12	43	24	15	No	149
11	"	"	"	14(a)	39	27	11	No	130
12	"	"	"	16(a)	40	28	12	No	127
13	0.40	"	19	9-1/2	38	26	15	No	134
14	"	"	"	12-1/2(a)	38	23	6	Yes	150
15	"	"	"	7-1/2	41	22	11	No	158
16	0.25	7/8	8-5/8	17-3/4(a)	42	27	22	No	134
17	"	"	"	15-3/4(a)	40	24	23	No	147
18	"	"	"	19-3/4(a)	41	27	12	No	132
19	0.33	"	11-5/8	16-1/4(a)	42	27	11	No	133
20	"	"	"	14-1/4(a)	41	26	11	No	137
21	"	"	"	18-1/4(a)	42	26	14	No	138
22	0.40	"	14	15(a)	42	27	12	No	133
23	"	"	"	13(a)	41	26	16	No	137
24	"	"	"	17(a)	43	26	14	No	139
25	0.50	"	17-9/16	11-1/4	45	26	13	No	141

Table II (cont'd)

	Charge Parameters				Results				
Charge	Charge Weight (lb)	Charge Diameter (in.)	Charge Length (in.)	Depth to Center of Gravity of Charge (in.)	Crater Diameter (in.)	Crater Depth (in.)	Bowl Diameter (in.)	Partial Camouflet (?)	Vulnerability Angle (deg.)
26	0.50	7/8	17-9/16	13-1/4[a]	46	26	13	No	142
27	"	"	"	15-1/4[a]	41	28	12	No	128
28	0.15	1/2	14-1/2	12	37	24	14	No	144
28A	0.30	3/4	13-1/2	7[b]		See Appendix C			--
29	0.15	1/2	15	13	40	24	11	No	147
29A	0.45	7/8	15-1/2	9[b]		See Appendix C			--
30	0.15	1/2	15	13	38	24	13	No	145
30A	0.45	7/8	15-1/2	9[b]		See Appendix C			--
31	0.15	5/8	10	15	32	23	12	No	145
31A	0.30	3/4	13-3/8	11[b]		See Appendix C			--
32	0.20	5/8	10	15	33	24	14	No	140
32A	0.30	3/4	13-3/4	11[b]		See Appendix C			--
33	0.15	5/8	10	15	37	21	15	No	161
33A	0.45	3/4	13-5/8	7[b]		See Appendix C			--
34	0.15	5/8	10	15	34	22	9	No	153
34A	0.20	5/8	13-1/8	10[c]		See Appendix C			--
34B	"	"	"	10[c]		" " "			--
34C	"	"	"	10[c]		" " "			--
35	0.15	5/8	10	15	37	24	16	No	144
36	0.15	5/8	10	14	41	21	11	No	163
36A	0.45	7/8	15-1/2	14[c]		See Appendix C			--
36B	"	"	"	14[c]		" " "			--
36C	"	"	"	14[c]		" " "			--
36D	"	"	"	14[c]		" " "			--
37	0.15	1/2	15	15	33	24	9	No	140

Table II (cont'd)

	Charge Parameters				Results				
Charge	Charge Weight (lb)	Charge Diameter (in.)	Charge Length (in.)	Depth to Center of Gravity of Charge (in.)	Crater Diameter (in.)	Crater Depth (in.)	Bowl Diameter (in.)	Partial Camouflet (?)	Vulnerability Angle (deg.)
38	0.15	1/2	15	16	33	25	9	No	134
39	0.15	5/8	10-1/8	15	36	21	12	No	161
40	"	"	"	16	33	22	12	No	153
41	"	"	"	15	32	25	8	No	133
42	0.15	1/2	15-1/8	9-1/2[d]	48	18	20	No	180
42A	"	"	"	9-1/2[d]		See Appendix C			--
42B	"	"	"	9-1/2[d]		"	"	"	--
42C	"	"	"	9-1/2[d]		"	"	"	--
43	0.20	5/8	13-3/4	13	32	25	11	No	133
44	"	"	"	13	33	22	11	No	153
45	"	"	"	14	32	20	11	No	166
46	0.50	7/8	16-1/2	18	46	29	16	No	129
47	0.75	13/16	28	22	46	41	15	No	90
48	1.20	15/16	34	22	94	46	27	No	118
49	1.20	"	34	29[a]	65	54	20	No	84
50	1.00	"	28	21-1/2[a]	47	45	14	No	82
51	"	"	28	22[a]	56	44	22	No	94
52	1.67	1-1/16	37	23[a]	61	48	18	No	91
53	"	"	37	28	87	52	31	No	104
54	1.50	"	32	27	69	49	18	No	96
55	1.50	"	32	23-1/2	94	46	31	No	118
56	1.25	"	27	20	66	39	24	No	115
57	1.25	"	27	21	60	38	24	No	112
58	1.25	"	27	19	60	40	21	No	107
59	2.00	1-3/16	35	27-1/2	75	48	21	No	103

Table II (cont'd)

Charge	Charge Parameters				Results				
	Charge Weight (lb)	Charge Diameter (in.)	Charge Length (in.)	Depth to Center of Gravity of Charge (in.)	Crater Diameter (in.)	Crater Depth (in.)	Bowl Diameter (in.)	Partial Camouflet (?)	Vulnerability Angle (deg.)
60	2.00	1-3/16	35	25[a]	62	50	21	No	88
61	2.00	"	35	25	66	51	23	No	90
62	1.75	"	31	23-1/2	62	41	17	No	107
63	1.75	"	31	28[a]	64	51	18	No	88
64	1.75	"	31	26	72	51	20	No	95
65	1.00	1-1/4	10-7/8	30	59	39	19	Yes	109
66	"	"	"	33	53	44	18	Yes	91
67	"	"	"	29	53	42	19	No	96
68	"	"	"	29	56	42	27	No	99
69	"	"	"	33	59	45	27	No	95
70	"	2.01[e]	"	30	58	42	15	Yes	101
71	"	"	"	33	54	45	20	No	90
72	"	"	"	29	55	43	23	No	95
73	"	"	"	29	59	43	36	No	99
74	"	"	"	33	59	45	23	No	95
75	"	2.06[e]	11-1/8	30	54	43	33	Yes	94
76	"	"	"	33	52	43	20	Yes	92
77	"	"	"	29	60	42	25	No	103
78	"	"	"	29	52	42	20	Yes	94
79	"	"	"	33	55	42	21	No	98
80	"	2.13[e]	11	30	55	43	21	No	95
81	"	"	"	33	53	45	20	No	89
82	"	"	"	29	62	41	30	No	107
83	"	"	"	29	57	42	18	No	100
84	"	"	"	33	60	46	39	Yes	94

Table II (cont'd)

(a) Charges tamped by filling the borehole with compacted soil.

(b) Charges used to deepen and enlarge an existing crater. For example, Charge 28A was placed in a borehole in the bottom of the crater formed by Charge 28. In Appendix C, dotted lines are employed to show where the initial crater was before it was obliterated by the secondary charge(s).

(c) Similar to note (b) except that the secondary charges were used in multiple. They were spaced at radial angles of 120 degrees and 90 degrees for groups of 3 and 4 charges, respectively.

(d) These four charges placed in a grid pattern 8 inches square.

(e) Charges not circular so these dimensions represent diameter of hole required to receive these charges.

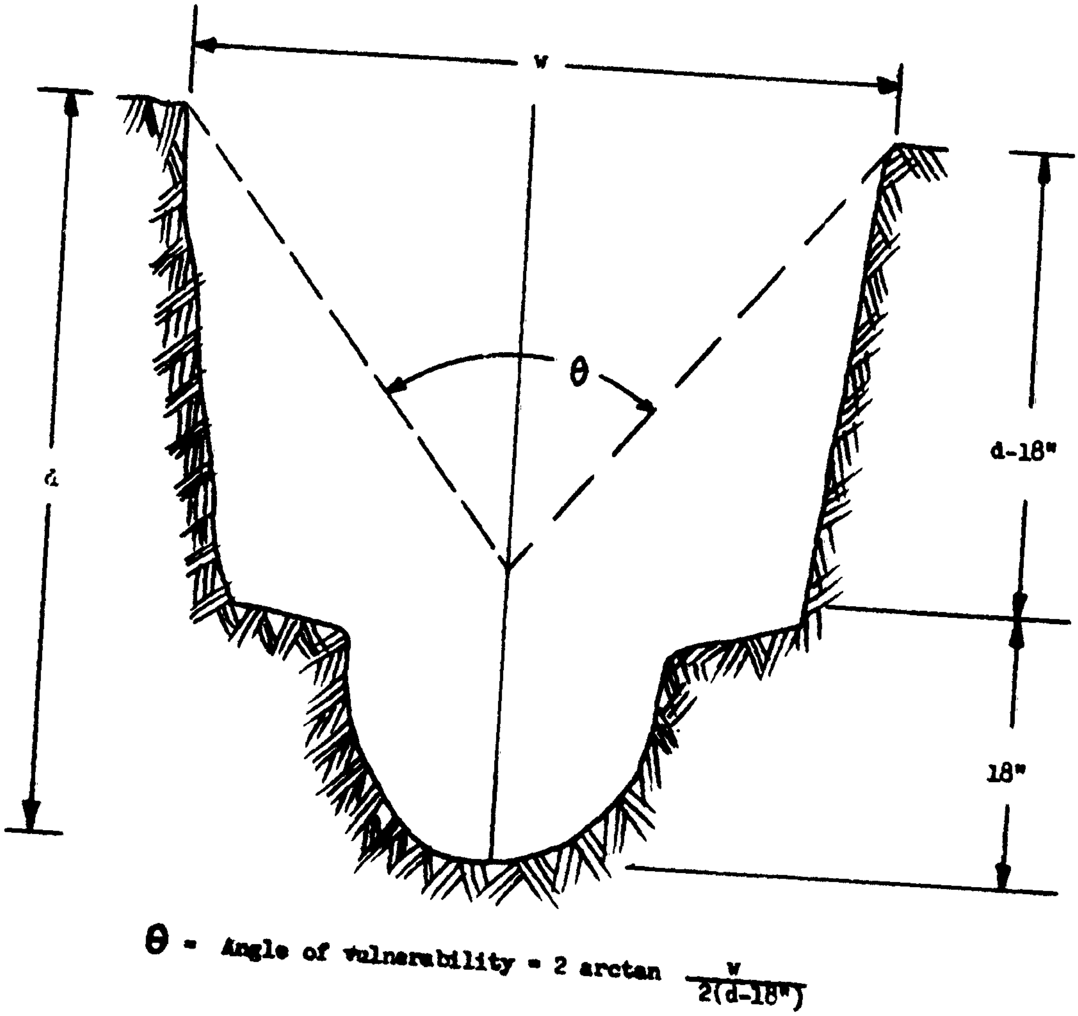
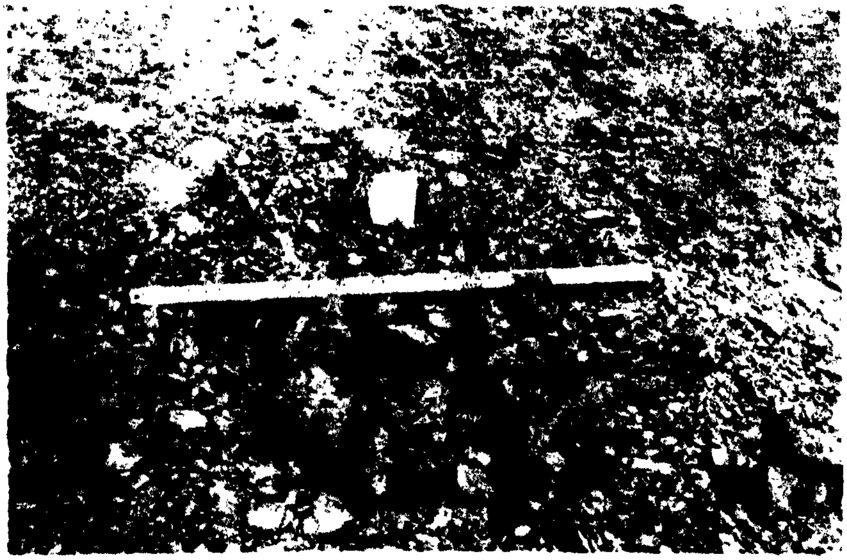


Fig. 18. Angle of vulnerability.

The charges incorporating a linear shaped-charge configuration (Figs. 6 and 7) were as follows: Type B, 70-74; Type C, 75-79; and Type D, 80-84. For evaluation, they were compared with a cylindrical charge (Type A, 65-69).

Profiles of all craters are contained in Appendix C.



G6560

Fig. 19. Surface rupture caused by typical lightweight (1/2 pound or less) cratering charge.

G6558

Fig. 20. Cleaned crater resulting from typical lightweight (1/2 pound or less) cratering charge.

III. DISCUSSION

5. Examination of Test Methods. A review of the test methods indicates they were adequate, within the scope, for evaluation of the sequential use of two charges for cratering. However, the scope was restricted within certain limits. Additional work which may be conducted in the future will provide precise information as to the value of tamping the cratering charges, shaped-charge cone angle, explosive types, and cratering charge configuration.

The experimental shaped charges were not optimum because of inconsistent performance due to cone quality and explosive loading variations. However, for the comparative evaluations involved, optimum shaped charge performance was not deemed necessary.

All cratering charges were initiated from the top for safety and simplicity. No evaluation of top versus bottom initiation was undertaken. The necessity of providing additional fusing length or arming the charge before it is placed obviates the employment of bottom initiation. An explosive device to be operated by a nondemolition-trained soldier should not require extensive handling after it is armed. In addition, the maximum reduction of bulk requires that time fusing be no longer than that required for safety.

The inherent heterogeneousness of soil makes it difficult to evaluate explosive effects. Tamping, i. e., compacting the soil backfill above the cratering charge, was evaluated, but the number of tamping tests was not sufficient upon which to base a conclusion. Tamping should be evaluated further in future tests.

No attempt was made during these tests to develop a firing system for the charges.

6. Analysis of Test Results.

a. Shaped Charges. For the formation of pilot holes for cratering charges, the shaped charge which forms a wider-diameter hole at a specified depth is more valuable than one which forms a deeper hole overall but which is narrower at the same depth. From this basis, a larger cone angle, say 60 to 90 degrees, is more advantageous since it will cut a wider though shorter hole than will a smaller cone angle, say 20 to 50 degrees, other things being equal.

Table III contains an analysis of the shaped-charge firings. The mean results have been determined according to type of charge and standoff and also for explosive-loaded-height variation of the experimental charges. The 90C charges (1-15) gave performance

Table III. Analysis of Shaped-Charge Firings

Charge Type	Charge Parameters: Quantity of Charges	Cone Diameter (in.)	Loaded Height above Apex (in.)	Stand-off (cal.)	Mean of Results: Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
90C (1-15)	3	4	3/4	Varies	48	3	40
" "	4	"	1	"	47	4	39
" "	4	"	1-1/4	"	46	4	38
" "	4	"	1-1/2	"	48	4	37
90C (1-15)	8	4	Varies	1.00	45-1/2	3-1/2	36
" "	6	"	"	1.25	48-1/2	4	41
" "	1	"	3/4	1.81	50	4	40
70C(16-30)	3	3-15/16	3/4	Varies	43	3-1/2	35
" "	4	"	1	"	40	3	29
" "	4	"	1-1/4	"	43	3-1/2	30
" "	4	"	1-1/2	"	40-1/2	2-1/2	31
70C(16-30)	5	3-15/16	Varies	1.00	42	3	32
" "	4	"	"	1.28	42	3	36
" "	2	"	"	1.72	39-1/2	3	29-1/2
" "	4	"	"	2.00	42	3	29
70C(31-48)	4	3-5/8	1	Varies	43	4	34
" "	4	"	1-1/4	"	42-1/2	4	29
" "	5	"	1-1/2	"	40	4	22
" "	5	"	1-3/4	"	35	5	18

Table III (cont'd)

	Charge Parameters				Mean of Results		
Charge Type	Quantity of Charges	Cone Diameter (in.)	Loaded Height above Apex (in.)	Stand-off (cal.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
70C (31-48)	2	3-5/8	Varies	1.00	33	4	20
" "	4	"	"	2.00	42	5	28
" "	4	"	"	2.50	39	4	29
" "	4	"	"	3.00	39	4	22
" "	4	"	"	4.00	43	4	25
90C (49-66)	4	3-11/16	1	Varies	42-1/2	3-1/2	22-1/2
" "	4	"	1-1/4	"	40	2-1/2	28
" "	5	"	1-1/2	"	37-1/2	3	28
" "	5	"	1-3/4	"	42-1/2	3-1/2	23-1/2
90C (49-66)	2	3-11/16	Varies	1.00	30	3-1/2	22
" "	4	"	"	2.00	42	2-1/2	28-1/2
" "	4	"	"	2.50	42-1/2	2-1/2	29
" "	4	"	"	3.00	43	4	19-1/2
" "	4	"	"	4.00	40	3	25-1/2
70A (67-78)	1	4	Varies	2.00	31	6	14
" "	1	"	"	3.00	29	4	20
" "	1	"	"	4.00	28	3	19
" "	1	"	"	5.00	31	6	10
" "	1	"	"	5.50	36	5	21
" "	1	"	"	6.00	40	4	27
" "	1	"	"	6.50	41	3-1/2	31
" "	1	"	"	7.00	34	5	27
" "	3	"	"	7.50	39	4	34
" "	1	"	"	8.00	35	4	29

Table III (cont'd)

Charge Type	Charge Parameters: Quantity of Charges	Cone Diameter (in.)	Loaded Height above Apex (in.)	Stand-off (cal.)	Mean of Results: Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
60LA (79-83)	5	3-1/2	Varies	Varies	29	2-1/2	17
60LT (84-88)	5	3-1/2	Varies	Varies	29-1/2	2-3/4	23
60L (89-93)	5	3-1/2	Varies	Varies	24-1/2	2-3/4	12
70Ct (94-105)	3	4-1/16	3/4	Varies	40	3-1/2	30
" "	3	"	15/16	"	44	4	27
" "	3*	"	3/4	"	38	7	15
" "	2*	"	15/16	"	40-1/2	5	21-1/2
" "	1*	"	7/8	2.50	35	3-1/2	19
70Ct (94-105)	2	4-1/16	Varies	2.00	42-1/2	5	32
" "	1*	"	"	2.00	32	10	14
" "	2	"	"	2.50	38	2-3/4	25-1/2
" "	3*	"	"	2.50	40	5	18
" "	2	"	"	3.00	44-1/2	4-1/4	27-1/2
" "	2*	"	"	3.00	39	5-1/4	19-1/2
70Ctl (106-17)	3	4-1/8	5/8	Varies	59	4	35
" "	3	"	15/16	"	56	5	39
" "	3*	"	3/4	"	52	4-1/2	34
" "	2*	"	15/16	"	52-1/2	5-1/4	26
" "	1*	"	7/8	2.50	43	3	23

Table III (cont'd)

Charge Type	Charge Parameters: Quantity of Charges	Cone Diameter (in.)	Loaded Height above Apex (in.)	Stand-off (cal.)	Mean of Results: Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
70Ct1 (106-17)	2	4-1/8	Varies	2.00	54-1/2	4-1/4	31
" "	1*	"	"	2.00	45	5	30
" "	2	"	"	2.50	59-1/2	4-1/2	40-1/2
" "	3*	"	"	2.50	52	4	30
" "	2	"	"	3.00	58-1/2	4-1/4	40
" "	2*	"	"	3.00	52	4-3/4	29
70Ct2 (118-29)	3	4-1/8	5/8	Varies	53	3	42
" "	3	"	15/16	"	56	3-3/4	37-1/2
" "	3*	"	5/8	"	54	3	37-1/2
" "	3*	"	7/8	"	49	3	33
70Ct2 (118-29)	2	4-1/8	Varies	2.00	57-1/2	3	44-1/2
" "	2*	"	"	2.00	51-1/2	3-1/4	33
" "	2	"	"	2.50	56	3-1/4	38-1/2
" "	3*	"	"	2.50	52	3	36
" "	2	"	"	3.00	50	3-3/4	36
" "	1*	"	"	3.00	47	2-1/2	37
70Ct3 (130-41)	3	4-1/4	5/8	Varies	45-1/2	3-3/4	22
" "	3	"	7/8	"	56	2-3/4	29
" "	3*	"	5/8	"	40	2-2/3	24
" "	3*	"	7/8	"	41-1/2	2-1/2	29

Table III (cont'd)

	Charge Parameters				Mean of Results		
Charge Type	Quantity of Charges	Cone Diameter (in.)	Loaded Height above Apex (in.)	Stand-off (cal.)	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
70Ct3 (130-41)	2	4-1/4	Varies	2.00	52-1/2	2-3/4	36-1/2
" "	2*	"	"	2.00	42	2-1/4	30
" "	2	"	"	2.50	53	3	23
" "	3*	"	"	2.50	40-1/2	2-3/4	26
" "	2	"	"	3.00	46-1/2	4	16-1/2
" "	1*	"	*	3.00	38	2-1/2	23
80Ct3 (142-53)	3	3-3/4	3/4	Varies	42	2-1/4	30
" "	3	"	1	"	42-1/2	2-1/2	33-1/2
" "	3	"	1-1/4	"	49	3	33
" "	1*	"	7/8	"	36	2-1/2	22
80Ct3 (142-53)	3	3-3/4	Varies	2.00	46	3	27
" "	3	"	"	2.50	43	2-1/2	34
" "	1*	"	"	2.50	36	2-1/2	22
" "	3	"	"	3.33	45	2-1/2	36
60Cq (152-60)	2	3-1/2	7/8	2.00	54	2	29
" "	2	"	1	"	52-1/2	3-1/4	42-1/2
" "	2	"	1-1/8	"	48	3	41
" "	2	"	1-1/4	"	50-1/2	3-1/2	36-1/2
" "	1	"	1-3/8	"	52	5	23
Tapper (161-79)	3	1-3/4	---	2.00	22	1	18
" "	11	"	---	2.29	23-1/2	1-1/8	20
" "	3	"	---	2.50	22	1	19
" "	2	"	---	3.00	24	7/8	20

Table III (cont'd)

Charge Type	Charge Parameters: Quantity of Charges	Cone Diameter (in.)	Loaded Height above Apex (in.)	Stand-off (cal.)	Mean of Results: Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
Perforator (180-84)	5	1-9/16	---	2.57	14	1/2	13
Perforator (185-89)	5	1-9/16	---	2.57	16	1/2	13

* Charges loaded with paste explosive instead of Composition C-4.

indicating that both low standoff and the lowest explosive-loaded-height are best. Note that case diameter exceeded cone diameter by 1/2 inch. The 70C charges (16-30) contained comparable explosive amounts even though the container diameter was 1/4 inch less than the 90C charge. Again, however, the lowest explosive-loaded-height and low standoff were the best performers. For these charges, a standoff of 1.25 calibers and an explosive-loaded-height of 3/4 inch above cone apex appears to be optimum among those tested.

The 70C charges (31-48) and the 90C charges (49-66) show an optimum standoff of 2 to 2.50 calibers and an optimum explosive-loaded-height of 1 to 1.25 inches above cone apex. The overall performance is inferior to that of charges 1-30 which correlates with smaller cone diameter.

The results of the 70A charges indicate that a standoff of approximately 7 calibers is optimum. Less than 6 calibers is unsatisfactory. Six calibers is equal to 24 inches total which makes the charge have a high center of gravity and be unstable under wind loading if not fastened. Aluminum cones do not appear desirable for boring soil.

Examination of the results of the lead and eutectic lead charges shows poor and erratic performance. Apparently, about 6 calibers is the best standoff (Table I) and the eutectic lead tin cones appear to be the best.

Charges 94-153 show the inferiority of performance of paste explosive vs Composition C-4 (Table IV). Even though the paste is easier to load than Composition C-4, its lower detonation rate makes it a second choice. Also, the paste was not of uniform density throughout,[2] thereby causing a reduction in performance of the shaped charge.

The optimum explosive-loaded-height above cone apex for charges 94-153 varied somewhat from charge type to charge type (Table III). Generally speaking, the 5/8- to 3/4-inch height gave as good or better performance than the 7/8- to 15/16-inch heights indicating as before (Report 1619-TR) that a major buildup of explosive above cone apex is undesirable.

The variable standoff data for charges 94-153 is inconclusive. For the range shown, 2 to 3.33 calibers, the average

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2. J. A. Dennis, Improvised Shaped Charges with Paste Explosive Filler, Report 1710-TR (Fort Belvoir, Va.: U. S. Army Engineer Research and Development Laboratories, 19 March 1962).

Table IV. Comparison of C-4 and Paste Explosives

Shaped-Charge Parameters			Mean of Results		
Charge Type	Quantity of Charges	Type of Explosive	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
70Ct	6	C-4	42	3-3/4	28-1/2
"	6	Paste	38-1/2	5-3/4	18
70Ct1	6	C-4	57-1/2	4-1/2	37
"	6	Paste	50-1/2	4-1/2	29-1/2
70Ct2	6	C-4	54-1/2	3-3/8	40
"	6	Paste	51-1/2	3	35
70Ct3	6	C-4	51	3-1/4	25-1/2
"	6	Paste	41	2-1/2	26-1/2
80Ct3	9	C-4	45	2-1/2	32
"	1	Paste	36	2-1/2	22

performance is about the same for all calibers, making it apparent that 2 calibers will be adequate for the shaped-charge configuration shown.

A comparison of the variation in copper-liner thickness is contained in Table V. The charges are grouped in three breakdowns according to the type of explosive. Each of the three breakdowns show that the 70Ct2 (1/8 inch thick) gave the best performance although the difference in performance over the 70Ct1 (3/32 inch thick) was not immense. Actually, the 70Ct1 gave a greater total depth and usable diameter but was inferior in the important criterion of usable depth. The surprising result is that the 80Ct3 was superior to the 70Ct3 in usable depth, although it was inferior otherwise. The breakdown into each explosive type showed similarity except for the performance reversal of the 70Ct3 and 80Ct3 liners.

The results of the tests with quality copper cones (152-160) (Table III) and with only explosive-loaded-height above apex varying are inconclusive. Apparently, the variation in shaped charge performance due to hand-loading of the explosive is sufficient to prevent obtaining conclusive data from the few tests conducted.

Table V. Comparison of Cone Thickness Variation

Shaped-Charge Parameters				Mean of Results		
Charge Type	Cone Thickness (in.)	Quantity of Charges	Type of Explosive	Total Depth (in.)	Usable Diameter (in.)	Usable Depth (in.)
70Ct	1/16	12	Both	40-1/4	4-3/4	23-1/4
70Ct1	3/32	12	"	54	4-1/2	33-1/4
70Ct2	1/8	12	"	53	3-1/4	37-1/2
70Ct3	3/16	12	"	46	3	26
80Ct3	3/16	10	"	44	2-1/2	31
70Ct	1/16	6	C-4	42	3-3/4	28-1/2
70Ct1	3/32	6	"	57-1/2	4-1/2	37
70Ct2	1/8	6	"	54-1/2	3-3/8	40
70Ct3	3/16	6	"	51	3-1/4	25-1/2
80Ct3	3/16	9	"	45	2-1/2	32
70Ct	1/16	6	Paste	38-1/2	5-3/4	18
70Ct1	3/32	6	"	50-1/2	4-1/2	29-1/2
70Ct2	1/8	6	"	51-1/2	3	35
70Ct3	3/16	6	"	41	2-1/2	26-1/2
80Ct3	3/16	1	"	36	2-1/2	22

The Jet Tapper gave consistent results with standoffs varying from 2 to 3 calibers indicating again that 2 calibers is sufficient for large-angled copper liners.

The Jet Perforator tests show that a thin, low-density plate negligibly affects the formation and performance of a shaped-charge jet.

b. Cratering Charges. Proper employment of cratering charges necessitates placement at optimum depth to obtain maximum volume of soil loosened. The optimum depth is that depth at which the charge is just beginning to form a camouflet. At this depth, a balance seems to occur between the tendency of the explosive to either compress the soil horizontally and downward or heave it upward. Determination of the optimum depth of placement in the test soil was accomplished by plotting charge depth versus Composition C-4 charge weight in Fig. 21. The excessively deep charges and the shallow charges are identified separately with a best-fit curve drawn between the two groups. Although this curve covers a smaller range of charge weights, it is very similar to the curve plotted in

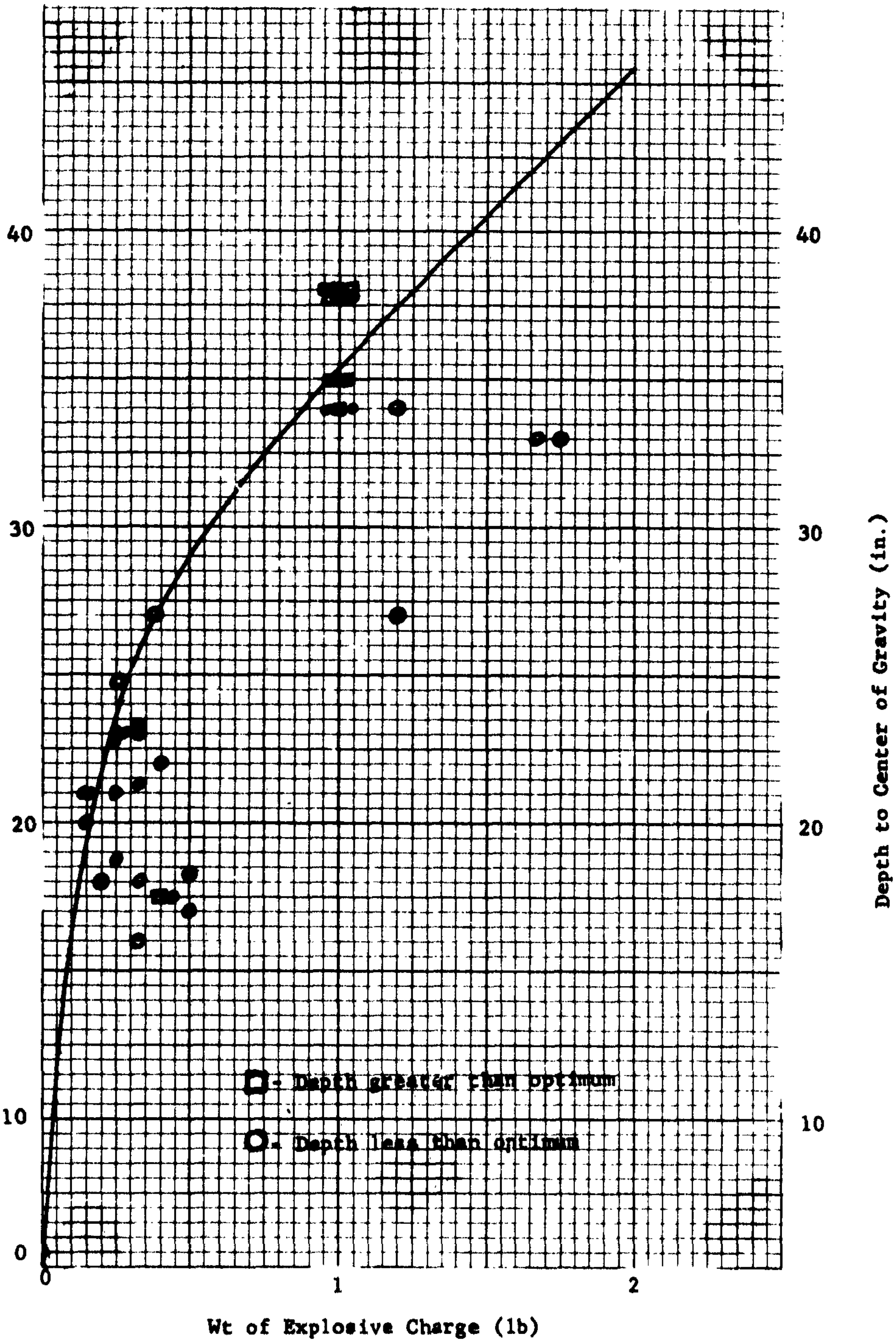

Fig. 21. Optimum depth of placement for various weights of Composition C-4 charges.

Report 1619-TR. This leads to a reiteration of the conclusion drawn in Report 1619-TR that, for the test soil, the optimum depth varies at the rate of 3 inches per 0.25 pound of explosive in the range of 1/2 to 3 pounds.

Analysis of the tamped charges versus the untamped charges indicates an advantage for the tamped charge. In some instances, no difference was observed between tamped and untamped charges at similar depths. A few tamped examples did show superior cratering ability and are cited in Table VI. In some instances (e. g., charges 63 vs 64 and 52 vs 55), the tamped charge actually gave inferior performance. Apparently, a larger amount of testing is needed to fully evaluate the increased crater volume obtained from a tamped charge.

Table VI. Tamped Versus Untamped Cratering Charges

Tamped Charge (No.)	Untamped Charge (No.)	Charge Weight (lb)	Advantage for Tamped Charge
5	4	0.33	Greater crater width at charge depth
6	10	0.33	Greater volume
11 - 12	10	0.33	Volume exceeded that expected from greater firing depth
17	7	0.25	Greater volume

Analysis of the craters resulting from the small charges (1-27) shows interesting results. A cratering charge of Composition C-4 used in conjunction with the Jet Tapper shaped charge to form a foxhole apparently should be 5/8-inch outside diameter and weigh in the range of 0.25 to 0.33 pound. Examination of the shaped-charge data shows minimum usable diameter of 7/8 inch. A cratering charge can be pushed into the hole beyond this usable depth but the diameter grows smaller. When the charge is pushed down, the bottom of the charge can approach the maximum depth of the shaped-charge hole, 27 inches. A foxhole lip diameter in excess of 30 inches is undesirable. A look at the 0.33-pound craters shows that the lip diameter consistently runs 36 inches or larger regardless of the depth of placement (maximum of 24 inches to bottom of charge). The 0.25-pound craters have lip diameters ranging from 32 to over 40 inches. However, charge 2 shows only 32-inch lip diameter, and its depth to bottom of charge is only 22 inches. The remaining 0.25-pound charges have lesser charge depths, except for Charge 9 which would cause greater lip diameters. Depth to center of gravity for one charge weight and hole depth can be increased only by reducing charge height which also requires an increase in charge diameter. An increase in charge diameter to 7/8 inch might be suitable although the major advantage would be to lower the center of gravity by allowing the charge to be shorter. An increase in charge weight beyond 0.25 pound does not seem advantageous because of the increasing lip diameter. The test site was clear of vegetation. A soil with vegetation would show smaller-diameter craters than did the cleared soil.

Results of the use of multiple charges (28-34, 36, 42) for forming foxholes indicated that doubling and tripling the weight of the second charge over the initial charge (28-31) is apparently not sufficient. Although the second charge did increase the initial crater, particularly the lower portion, the overall width in the lower portion is clearly inadequate. It would appear that doubling the depth of an existing crater by placing a charge below the initial crater bottom, while also forming a 30-inch minimum width, will require a charge at least five times as large and possibly ten times as large as the initial charge. Assuming 0.15 pound as adequate for the initial charge, a total of 1.65 pound might be required. It is also possible that a large secondary charge might cause an increase in crater lip diameter. Also, a much larger secondary charge would require a larger pilot hole as far as diameter is concerned. This would involve a shaped charge somewhat larger than the Jet Tapper, probably a charge of similar configuration but 1 inch greater cone diameter.

Charge 34 is an example of multiple secondary charges. Although the bottom width overall was adequate, the overall depth was inadequate. The bottom 8 inches consisted of three potholes separated by ledges. Either more or larger secondary charges are necessary when employed in this manner. For charges 36-36D, the secondary charges were increased by one over charge 34 and doubled in weight. With charges 36-36D, excessive lip diameter occurred, again with inadequate depth. Also, the potholes were still formed with ledges between. Charges 42-42C show how smaller weight charges can be placed close together to improve upon a single charge. However, four shaped charges would be needed to form the individual pilot holes. Possibly, a single shaped charge would permit a larger cratering charge at a greater depth thereby providing overall better configuration for equal explosive weight.

Examination of charges 47-64 shows that the charges are too long for the depth of placement since the lip diameters are quite large. Even though camouflets were prevented because the top of the charge was so near the surface, better crater configuration could be obtained by lowering the center of gravity of the charge without changing the depth to its bottom. As employed, a considerable portion of the explosive in the upper section of the charge is wasted in expanding the lip diameter. In addition, with the explosive spread over a long length, the ability to make a wide crater at charge depth is reduced. Except for the extra work involved in providing a larger-diameter pilot hole, the shorter charge is superior to the long charge for forming foxholes. Comparison of charges 50-51 with charges 65, 67-68, 70, 72-73, 75, 77-78, 80, and 82-83 which have equal weights and equivalent depths to bottom of charge shows the disadvantages of the long charge even though occasionally the short charges formed camouflets. The difference in crater volume is obvious, and the larger bottom width of the short charge crater is particularly advantageous.

The non-cylindrical cratering charges (65-84) were evaluated at three depths, 29, 30, and 33 inches. A comparison of the four types at each depth shows erratic performance resulting in no specific advantage for any one type. The linear-shaped charges created by the irregular configurations apparently have only a minor negligible effect, if any, upon crater configuration. Obviously, the critical thing is the general configuration of charge length and diameter; without major variation from this configuration, no changes in crater dimensions will occur.

Previous testing in this soil had led to the conclusion that the layered condition of the soil caused the noticeable demarcation between the soil which was compressed around and below the cratering charge and the soil which was heaved upward by the blast forces. It would appear, however, that the demarcation line represents purely a separation between compressive and tensile failure in the soil and does not necessarily indicate the plane between two distinct soil layers.

It would appear that the tensile failure loosens a greater volume of soil than does the compressive failure. Unfortunately, from a foxhole-forming standpoint, the tensile failure expands horizontally as well as vertically, thus causing excessive lip diameter in relation to overall desired crater width.

From an explosive-efficiency standpoint, the greater the volume of soil loosened the better the explosive. From this viewpoint, it would appear that charges would be placed so that compressive failure of the soil would be minimal and tensile failure would be maximum. Since a foxhole with vertical walls is desired, it is obvious that compressive failure would be the more desirable type of failure.

When additional charges are detonated below a previously formed crater (e. g., charge 33A), the soil failure is almost entirely compressive even though three times as much explosive was employed. Here, apparently the energy of the reflected tensile wave was insufficient to cause breakoff from the existing crater surface. Note also that the wave pattern from the explosion, charge 33A, would flow radially along the crater surface above the charge thereby reducing the tendency to form a reflected wave in this vicinity. The interaction of the compressive wave at the original ground surface occurs at such a distance that the reflected tensile stress is not enough to cause breakup of the soil at that distance.

7. Evaluation of Cratering Method. The application of the two-stage system for cratering foxholes was proved feasible in the first test series (Report 1619-TR). These additional tests show that smaller shaped charges can be employed to give adequate pilot hole formation. It is indicated that a quality shaped charge with an 80-degree (possibly 90-degree), $3\frac{1}{2}$-inch-diameter, copper, conical liner might be suitable for placing a $1\frac{1}{2}$-pound cratering charge at 36 inches to center of gravity. The conclusion drawn in Report 1619-TR concerning the use of a 70-degree cone is still valid pending further testing of 80- and 90-degree liners.

The use of small shaped and cratering charges to assist in excavating a foxhole is feasible. A total of 0.30 pound net explosive can provide a crater 30 inches in diameter and 27 inches deep in hard soils. The Jet Tapper is capable of providing 20-inch-deep clear holes in a tough soil. However, a rigid cratering charge of small diameter (5/8 inch or less) can be pushed virtually to the maximum total depth of 24 inches. Additional shaped-charge hole depth would be advantageous with a similar-sized shaped charge. However, the 80-degree liner of this charge matches very well with the data obtained from the improvised charges.

The long, small-diameter cratering charge has only two advantages. It requires a smaller-diameter pilot hole and essentially prevents the formation of camouflets. However, the short, wider-diameter charge gives much better foxhole configuration. Therefore, for a particular shaped charge, the largest-diameter cratering charge consistent with maximum explosive needed is most suitable, since maximum depth to center of gravity gives the better configuration. The previously stated conclusion in Report 1619-TR that a 2-inch-diameter cylinder, 9 inches long is appropriate is reiterated.

Tests indicated that the use of small charges in multiple to form foxholes is possible, but the number of charges required to deepen an initial hole is excessive. One large charge can be more efficient than several small charges, particularly so when one considers the extra effort required to employ the multiple charges. Making multiple pilot holes in an initial crater (see Table II, footnotes b and c) requires electrical detonation or single operation. In this situation, neither is desirable since the first requires demolition-trained personnel and the other requires too much time. Nonelectric firing can be performed by the average soldier but is not suitable for simultaneous firing because of variation in fuse burning time.

Tests seem to indicate that tamping the cratering charge would improve cratering efficiency and should be accomplished when time permits. The tamping can be best accomplished with a small-diameter rod. The actual amount of increase in percentage of crater volume is not definite, and further testing would be of value.

IV. CONCLUSIONS

8. Conclusions. It is concluded that:

a. The incorporation of linear-shaped charge capability in cratering-charge configuration has negligible effect upon crater shape and volume.

b. Due to waste of energy near soil surface, the cratering efficiency of long cratering charges (i. e., charges whose length is greater than one-half the bore-hole depth) is inferior to that of shorter charges.

c. Small shaped and cratering charges in a two-stage system, less than 1 pound gross, can be effectively used to assist in excavating a foxhole.

d. Paste explosive (modified Composition C-4) is applicable for expedient shaped charges because of its ease of loading; however, its performance is inferior to that of hand-loaded Composition C-4.

e. The scope of the tests performed provides the basis for future investigation of 80- and 90-degree shaped charge liners and cratering charge characteristics, configuration, and method of placement.

APPENDICES

APPENDIX A

AUTHORITY

Item 2158
CETC Meeting 327

RDT & E PROJECT CARD

1. TYPE OF REPORT: ☐ NEW ☐ FINAL ☒ REPLACES (No. & Date) 8-07-10-420, 31 Dec 59

REPORT CONTROL SYMBOL: CSCRD-1 (R-2)

2. PROJECT TITLE (TASK): Field Fortifications and Obstacles (U)

3. SECURITY OF PROJECT: Unclas

4. PROJECT NO.: 8F07-10-001

5. 8F07-10-001-02

6. REPORT DATE: 14 August 1961

7. BASIC FIELD OR SUBJECT: Mines and Obstacles

8. SUB FIELD OR SUBJECT SUB GROUP: Fortifications, Obstacles & Demolitions

9. CATEGORY: LC

10a. COGNIZANT AGENCY: Corps of Engineers

b. DIRECTING AGENCY: Mil Engr Div, R&D, OCE

c. REQUESTING AGENCY: Office, Chief of Engineers

11a. CONTRACTOR AND/OR GOVERNMENT LABORATORY: USA Eng Res & Dev Labs, Ft Belvoir, Va

b. CONTRACT NUMBER:

12. PARTICIPATION BY OTHER MILITARY DEPTS. AND OTHER GOVT. AGENCIES:

13. COORDINATION ACTIONS W/OTHER MILITARY DEPTS. & OTHER GOVT. AGENCIES:

14. SUPPORTING PROJECTS:

15. DATE APPROVED: 2 Apr 1954 by GSUSA

16. PRIORITY: 1-B

17. BUDGET CODE: 5600

18. EST. COMPLETION DATES

DEV.	65
ENGR TEST.	66
USER TEST	67
OPERATIONAL	68

19. EST. SUPPORT LEVEL

- ☐ UNDER $50,000
- ☒ $50,000 - $100,000
- ☐ $100,000 - $250,000
- ☐ $250,000 - $500,000
- ☐ $500,000 - $1,000,000
- ☐ OVER $1,000,000

20. CDOG 639a(1)

21. SPECIAL CODES:

22. REQUIREMENT AND/OR JUSTIFICATION

This project is expected to provide new or improved items of materiel, equipment, and techniques for increasing the efficiency and ease of handling and construction of field fortifications and obstacles, to facilitate the movement and defense of field forces in the theater of operation, assist in the attainment of their military objective, more adequately meet the threat of increase firepower and destructive potentialities of present weapons and modes of warfare, including atomic, and provide increased defense against massed infantry attacks. The improved or developed items will decrease losses of materiel and personnel, and warrant the assignment of a 1-B priority.

23. Brief of Project and Objective:

a. Brief:

(1) Objective:

This project is expected to improve present types and develop new types of field fortifications and obstacles, as well as equipment that will assist in the construction and erection of such items, and to provide additional protection and security to field forces in the theater of operations.

(2) Military Characteristics: Not applicable.

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b. Approach:

(1) Efforts will be made to improve the characteristics of field fortifications to increase the efficiency and ease of their usage, *i.e.*, in their transportation, handling, and construction. Special attention will be given to the use of prefabricated sections of stable and light material designed to facilitate transporting, handling, and erecting. Development of obstacles will be based on: (1) their independent use as a means to delay and embarrass the enemy and (2) as an auxiliary means of defense of field fortifications. Special consideration will be given to the development of prefabricated sections of steel obstacles such as hedgehogs and barbed wire. The potentialities of flame as an obstacle will be fully investigated, as also will be obstacles against amphibious assault and obstacles against airborne assaults. Coordination with employment of mine warfare will be considered.

(2) The accomplishment of the mission of this project shall be effected through six specific and successive phases:

1. Confirmation of requirements by the using agency (CONARC).

2. Investigation and evaluation by the developing agency, to determine the merits of possible approaches towards the solution of confirmed requirements.

3. Preparation of specific military characteristics.

4. Approval of the military characteristics by the using agency (CONARC).

5. Approval of the military characteristics by appropriate amendment and/or revision to this project through action of the Corps of Engineers Technical Committee.

6. Research and development in accordance with approved military characteristics.

c. Subtasks:

(1) Mechanical-Explosive Excavator.
(2) Field Fortifications Set.
(3) Multi-purpose Individual Shelter.
(4) Sprayed & Foaming Plast Fortifications.

d. Other Information:

(1) Scientific Research: None

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(2) References:

(a) Field Fortifications Manual, FM 5-15.

(b) (b) Item 1263, CETC Meeting No. 238, closing Project No. 8-07-06-001.

(3) Discussion: None.

APPENDIX B

SOIL TEST DATA FOR RANGE 1

Exhibit 1

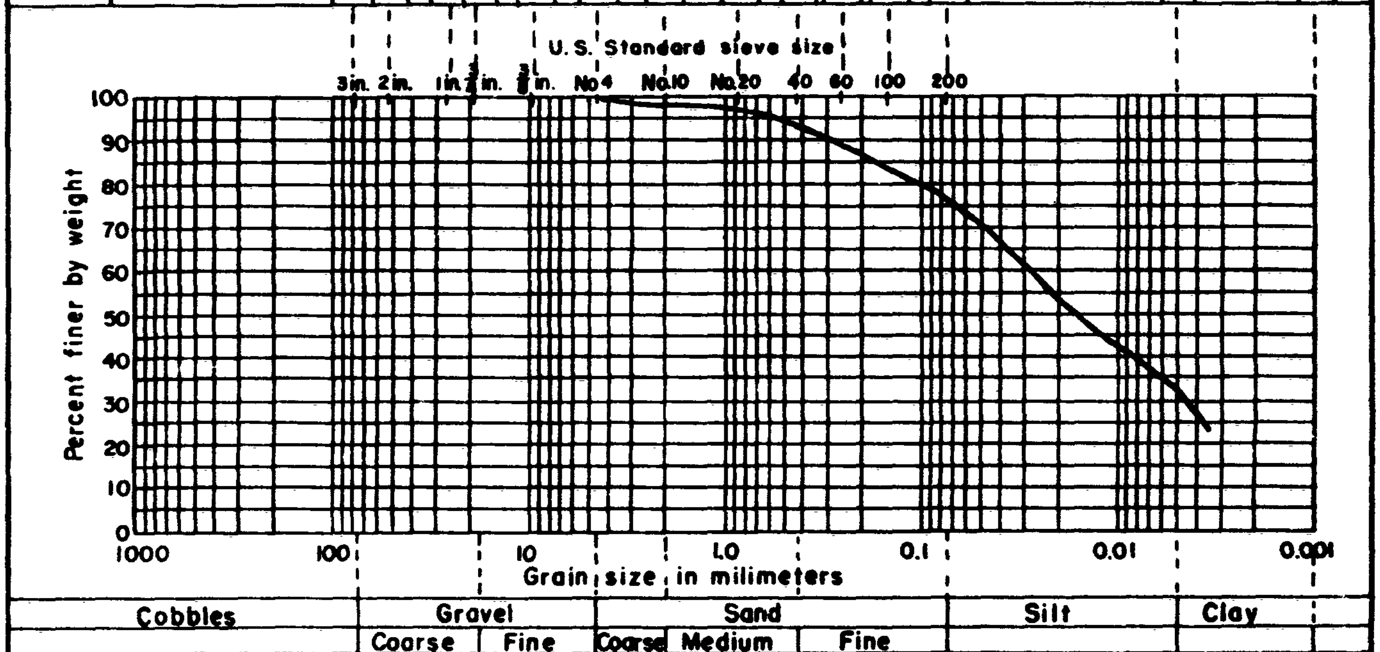
Depth from Surface (in.)	Dept of the Army Uniform Soil Classification	Density (lb/ft^3)	California Bearing Ratio (CBR) (%)
2	CL Lean clay	105	7
12	CL Lean clay	113	22
24	CL Sandy clay	113	27
36	CL Sandy clay	113	15
50	SM-SC Silty sand	144	83

Exhibit 2

Grain size distribution chart

Project No. 8-07-10-420 Location Range 1, Demolition Test Area, LPG Date Feb. 1958

Lab No. | Percent passing



Lab No.	Sta.	Depth	Field moisture	Field density	Sp.Gr.	LL	P I	Opt moisture	Max * density	U.S. Army Classification
		0-18"	16.0	113		35	15			CL - Lean Clay

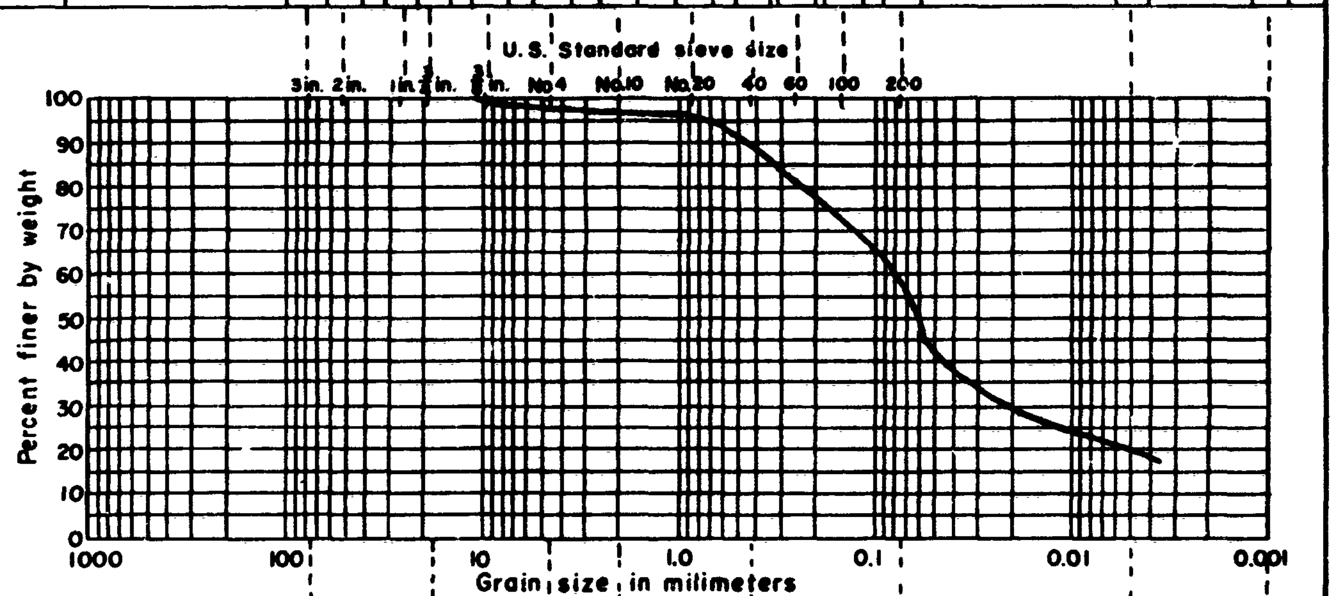
* Method used ---------------------

Exhibit 3

Grain size distribution chart

Project No. 8-07-10-420 Location Range 1, Demolition Test Area, EPG Date Feb. 1958

Lab No.	Percent passing



Cobbles	Gravel		Sand			Silt	Clay
	Coarse	Fine	Coarse	Medium	Fine		

Lab No.	Sta.	Depth	Field moisture	Field density	Sp.Gr.	LL	PI	Opt moisture	Max * density	U.S. Army Classification
		24"-48"	15.8	113		31	17			CL - Sandy Clay

* Method used ——————————

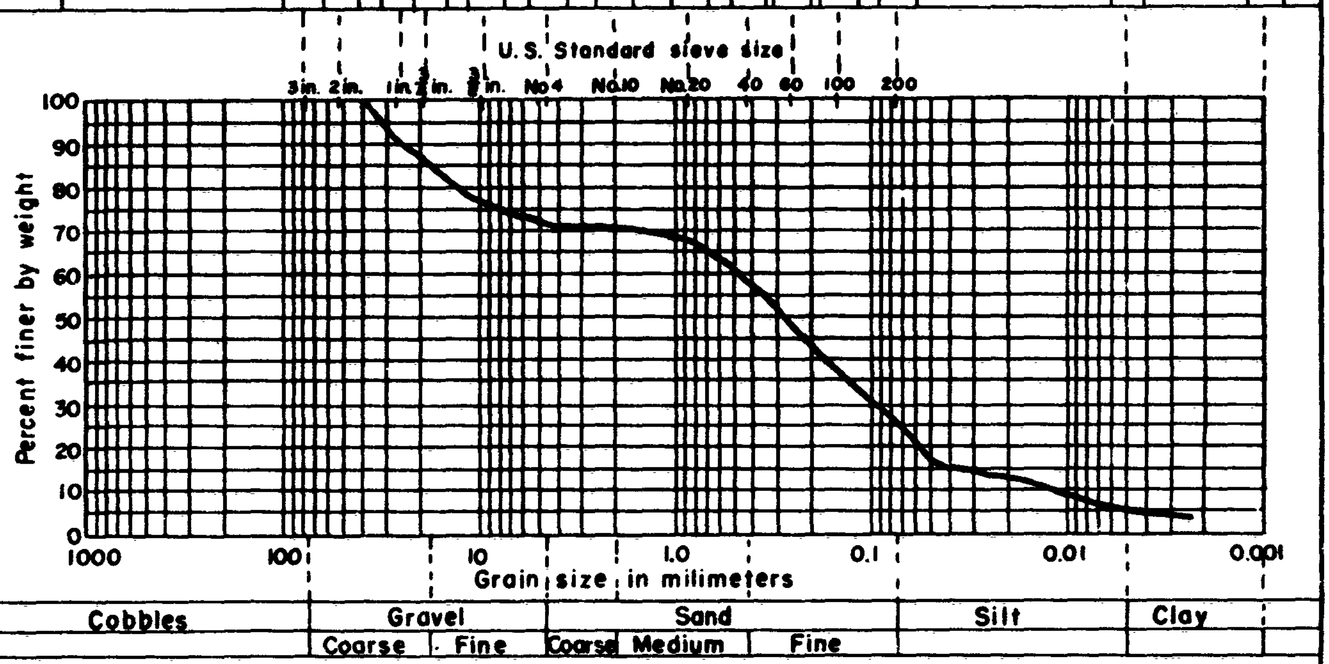
Exhibit 4

Grain size distribution chart

Project No. 8-07-10-420 Location Range 1, Demolition Test Area, EPG Date Feb. 1958

Lab No.

Percent passing

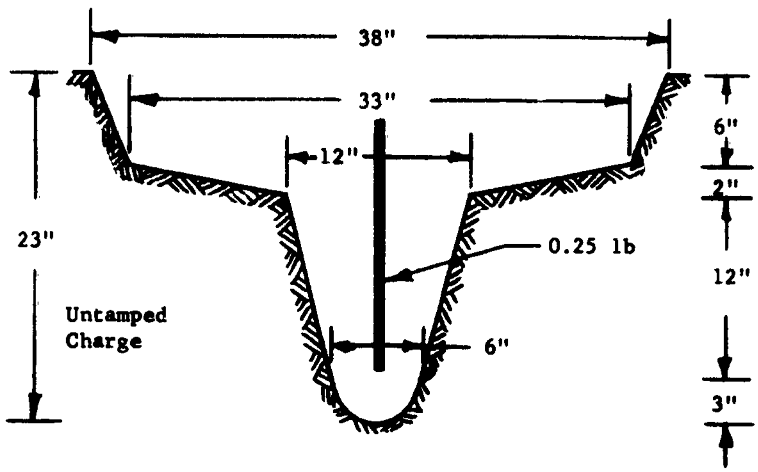


Lab No.	Sta.	Depth	Field moisture	Field density	Sp.Gr.	LL	P I	Opt moisture	Max * density	U.S. Army Classification
		+50"	8.1	144		19	4			SM-SC Silty Sand

* Method used

APPENDIX C

CRATER PROFILES



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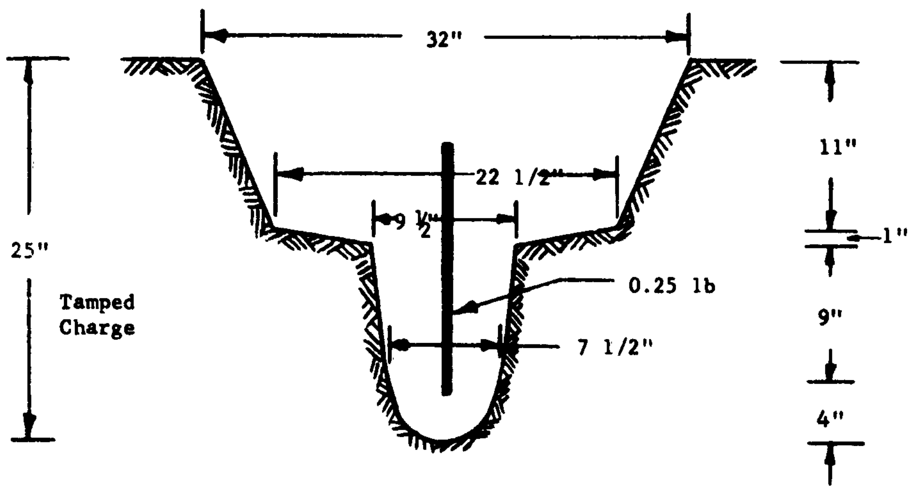

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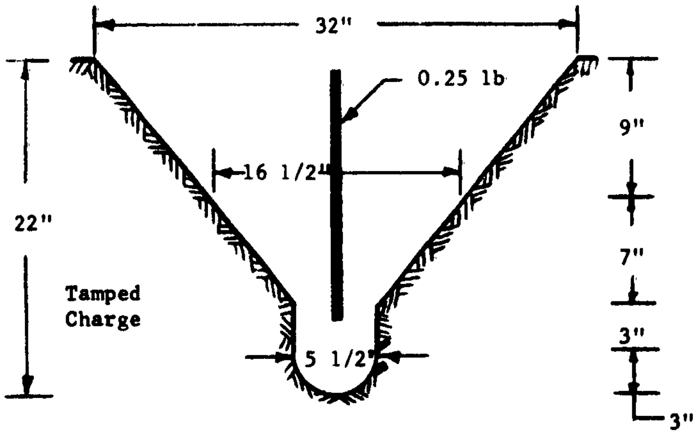

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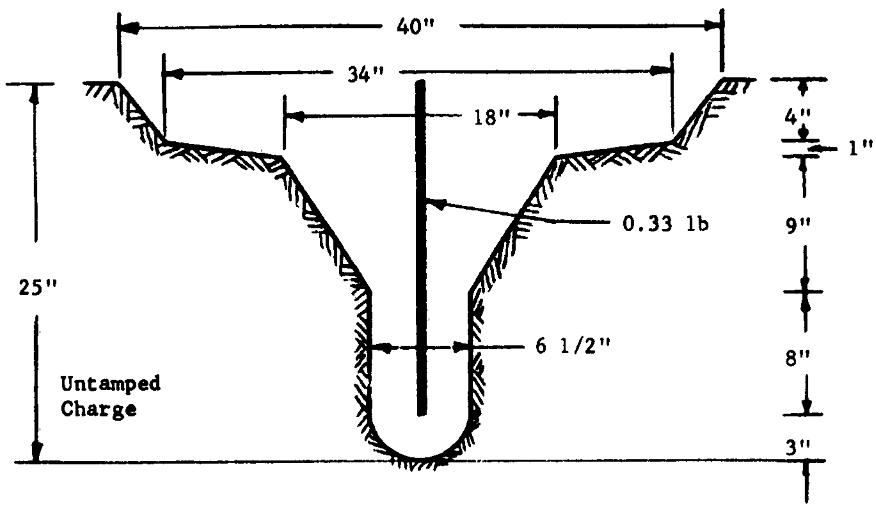

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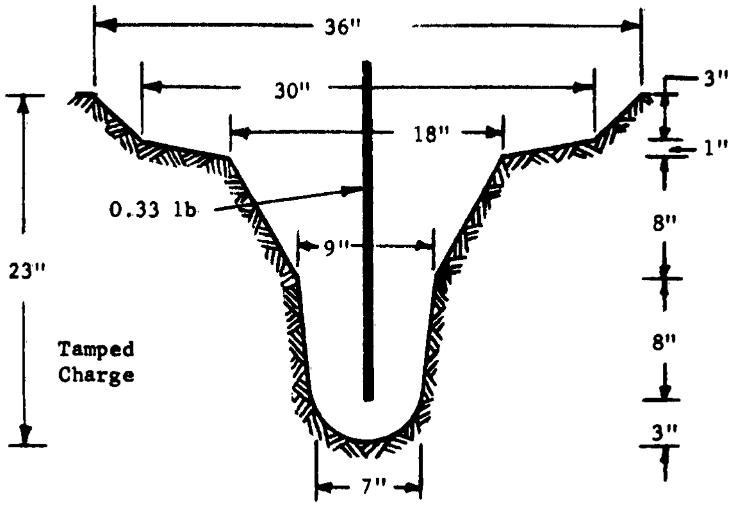

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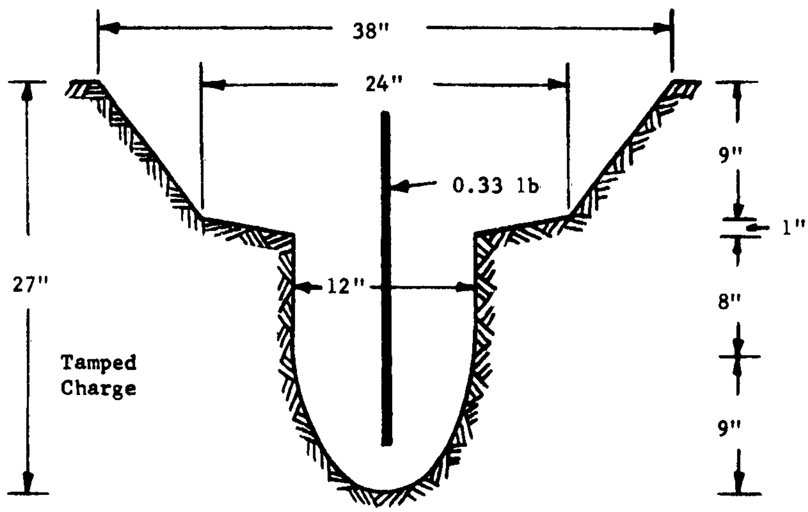

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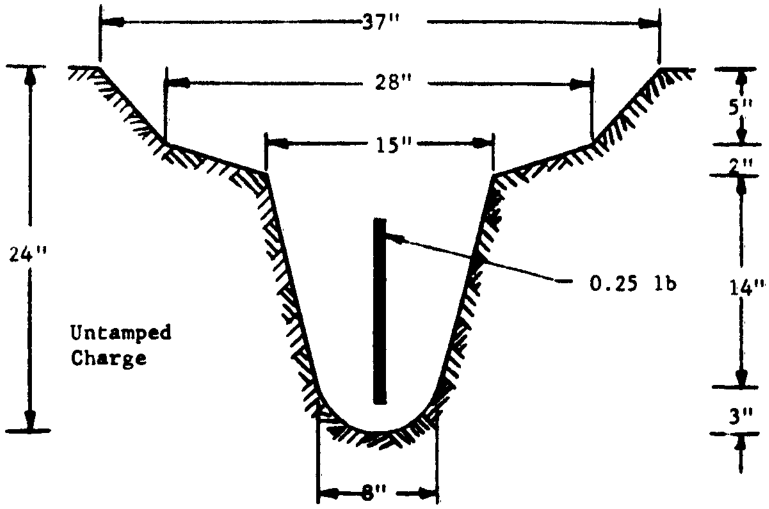

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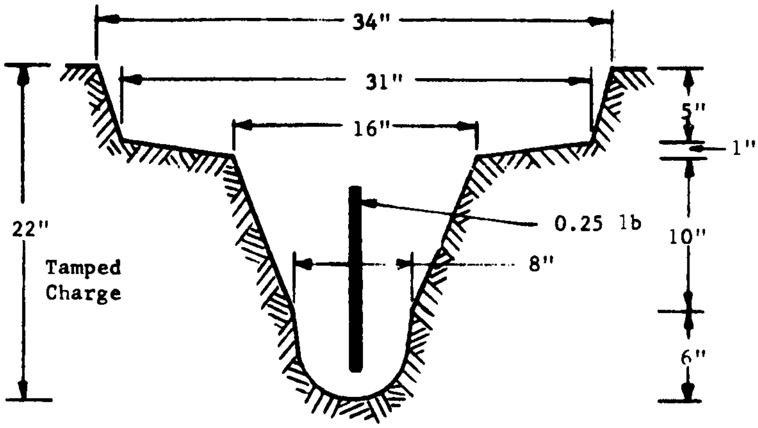

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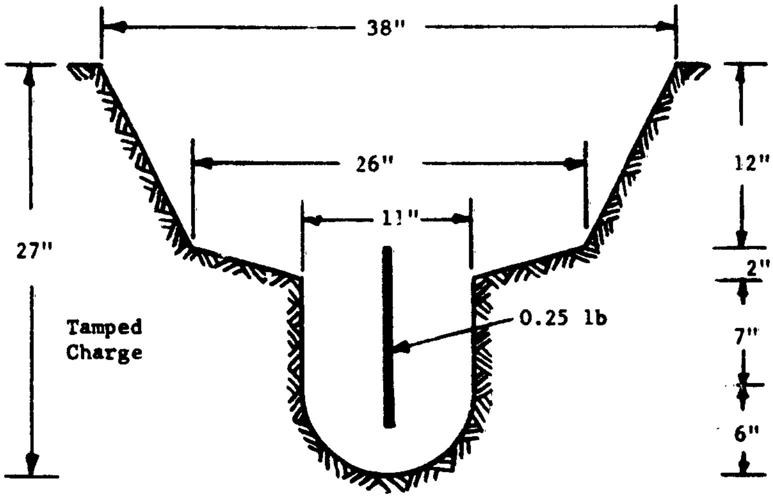

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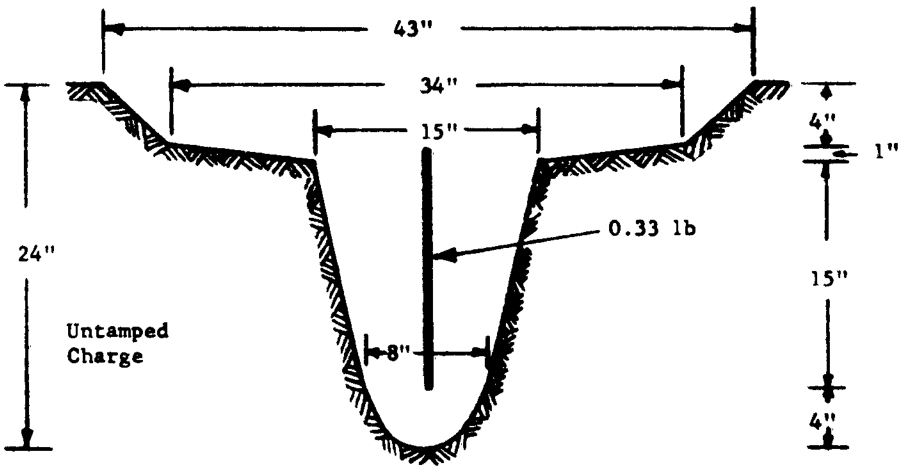

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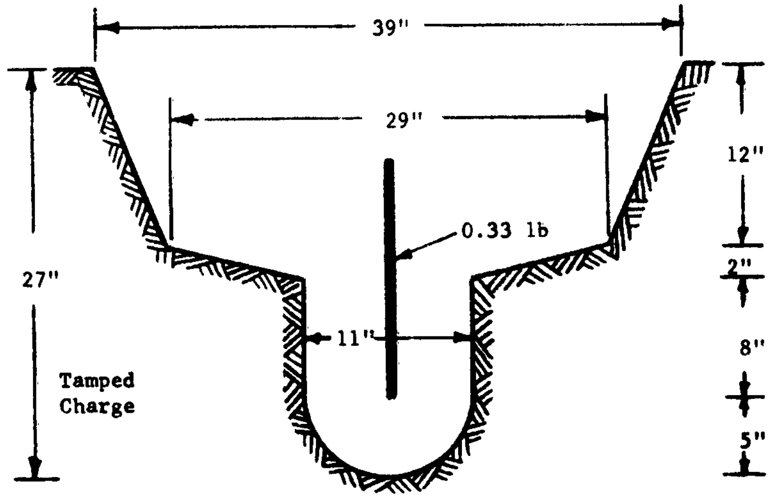

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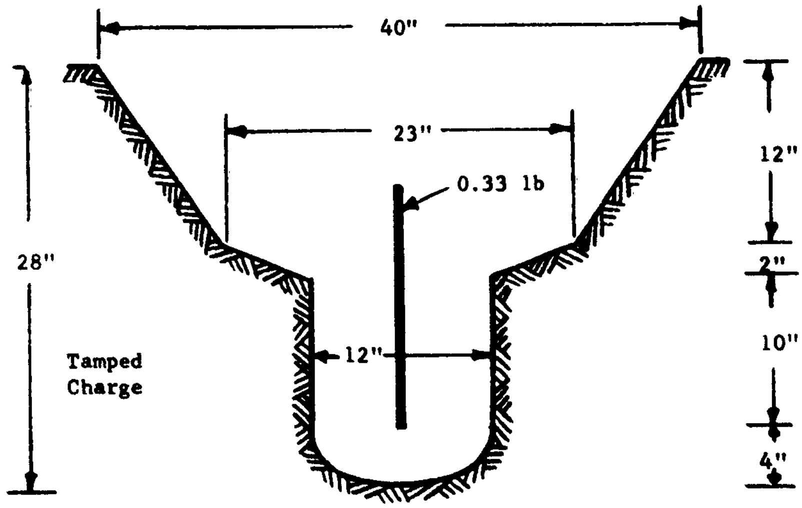

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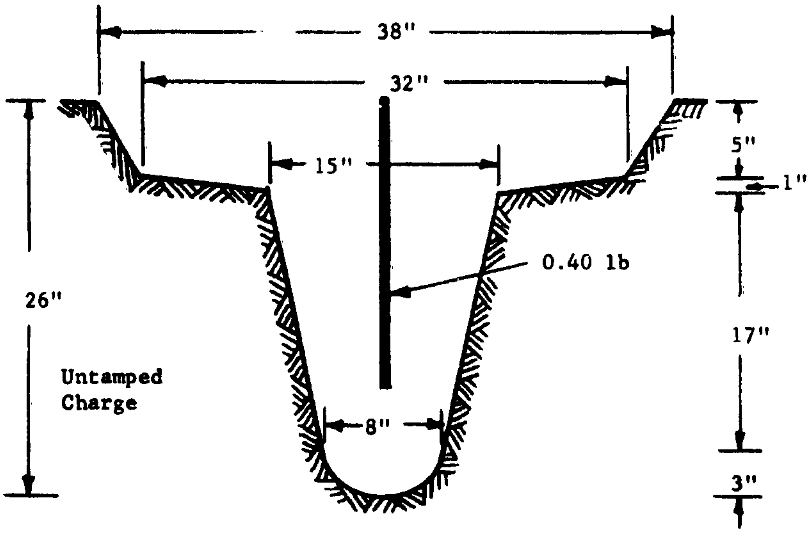

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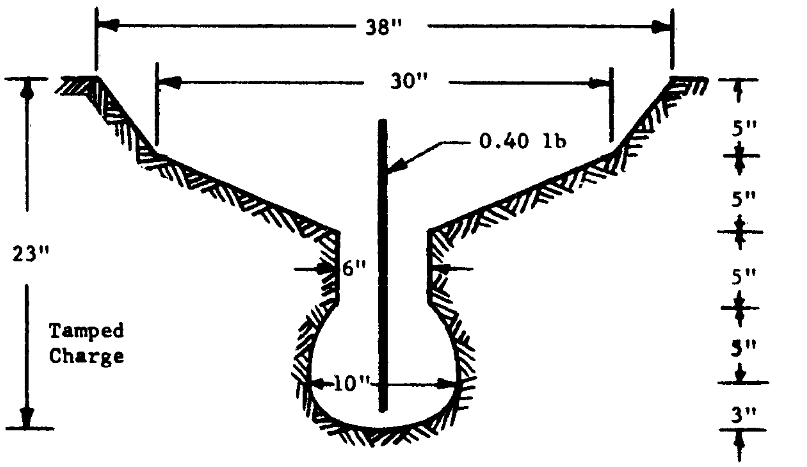

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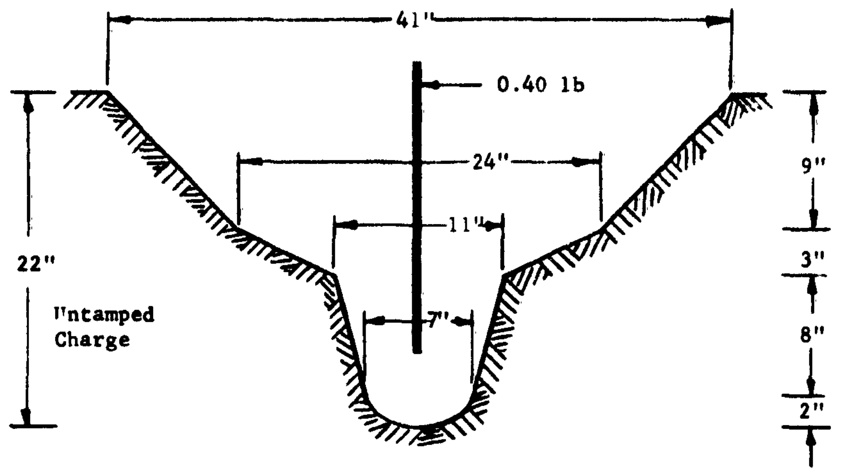

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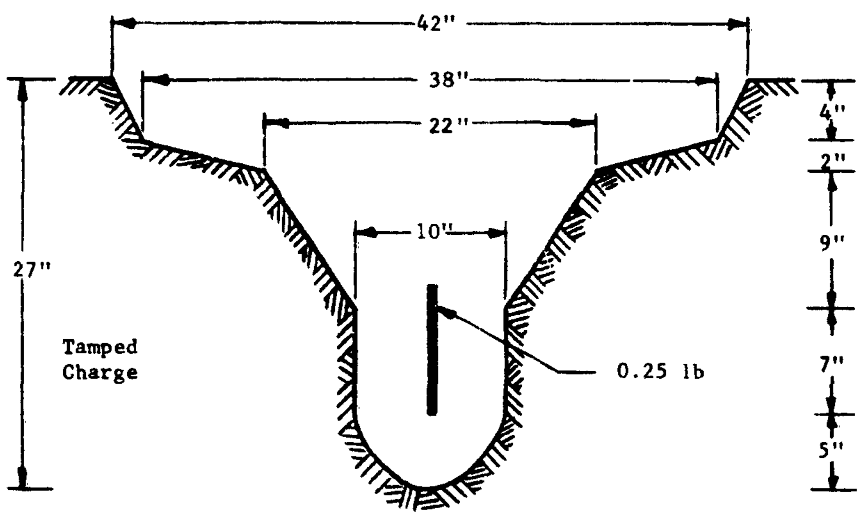

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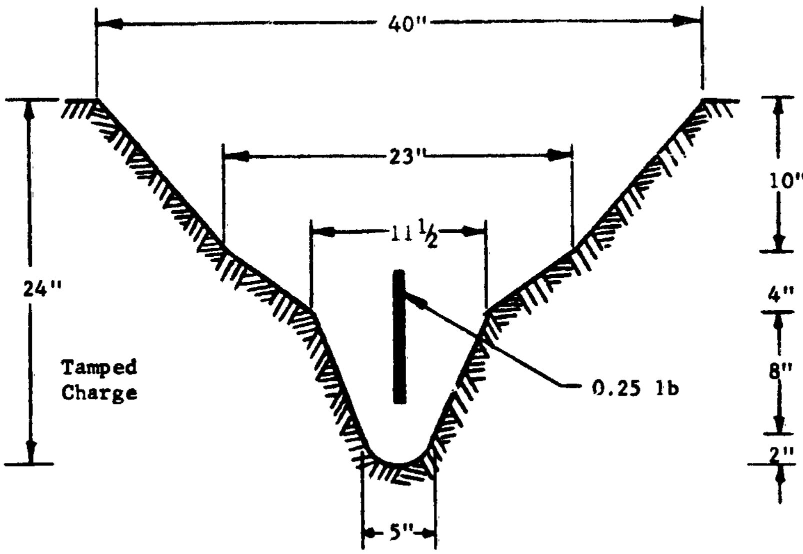

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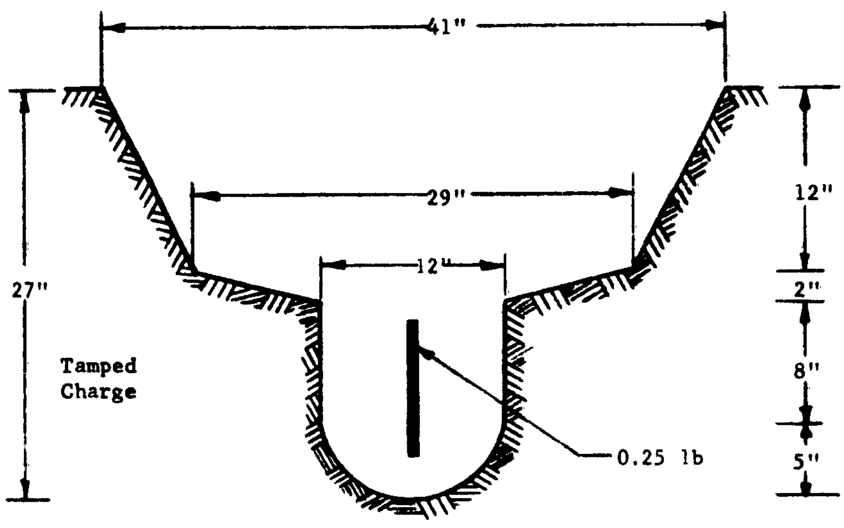

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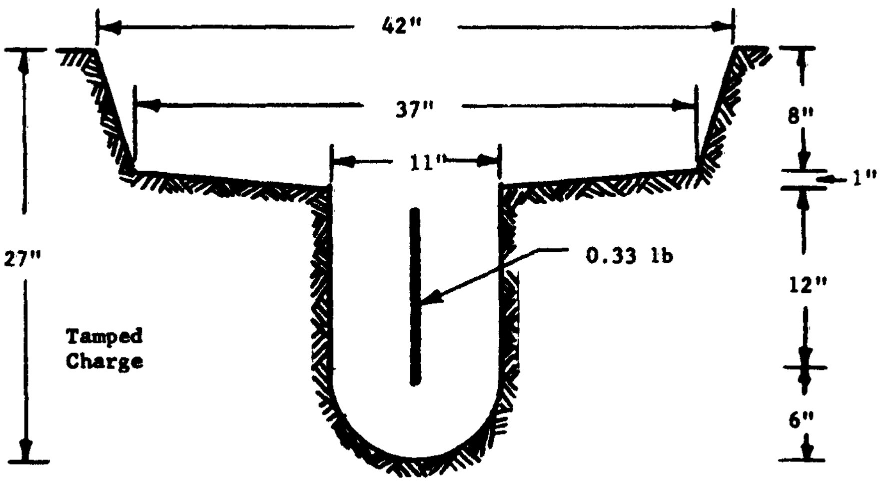

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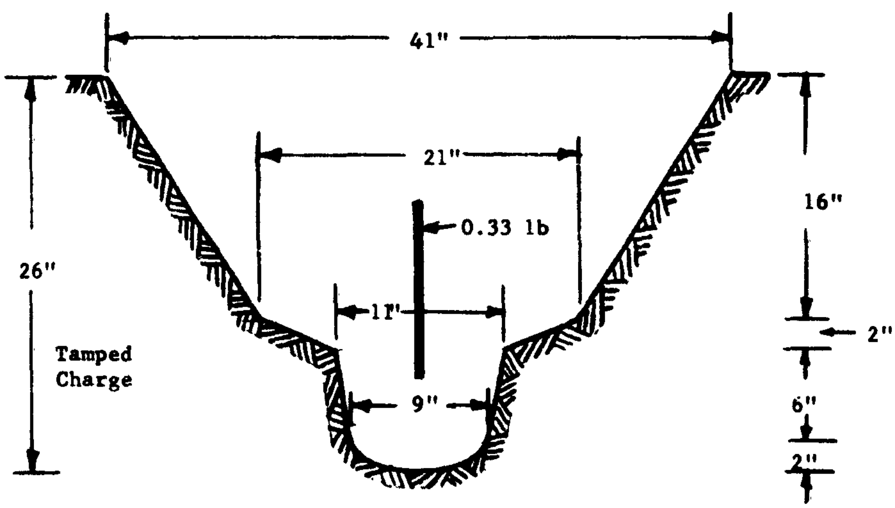

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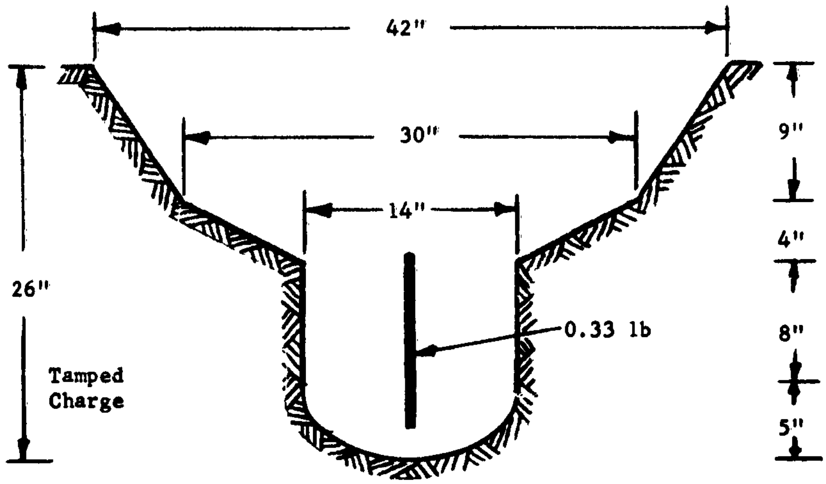

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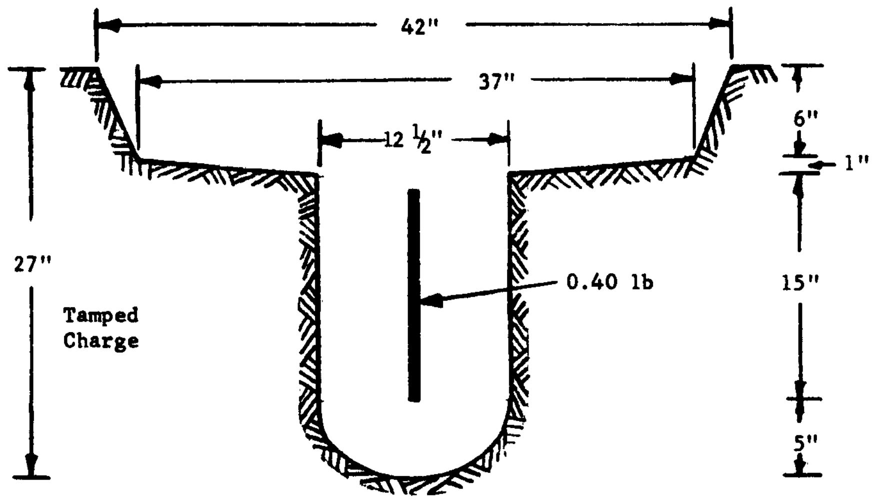

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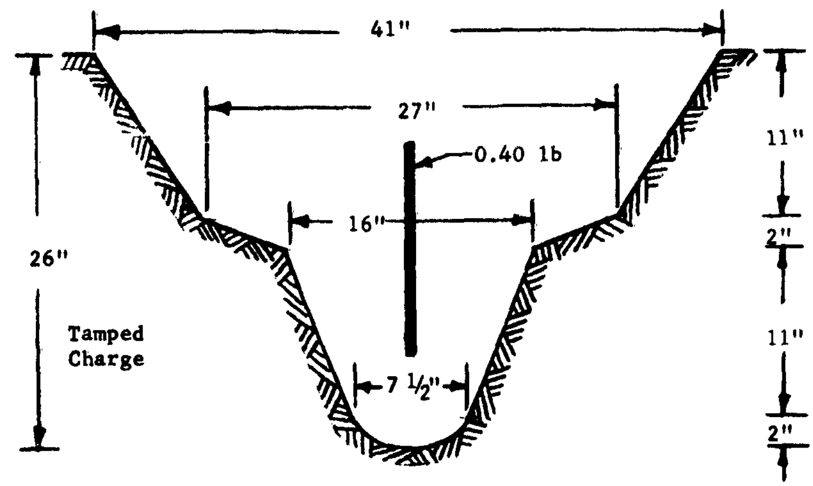

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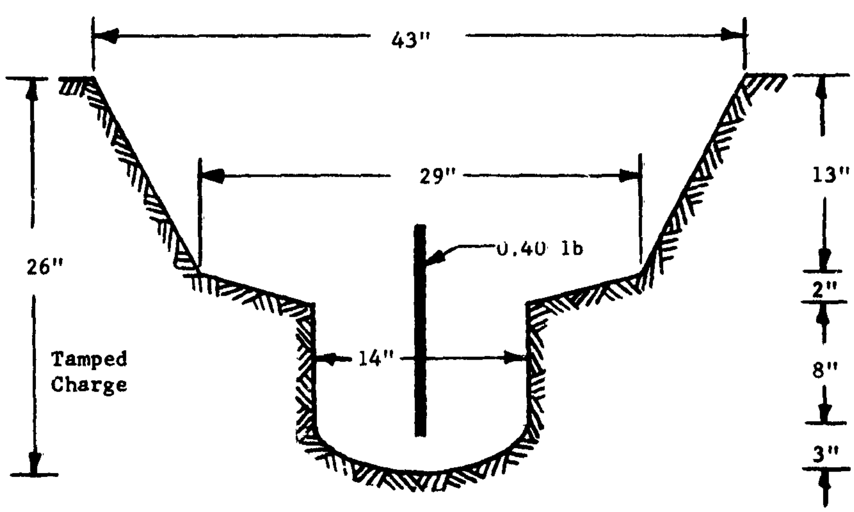

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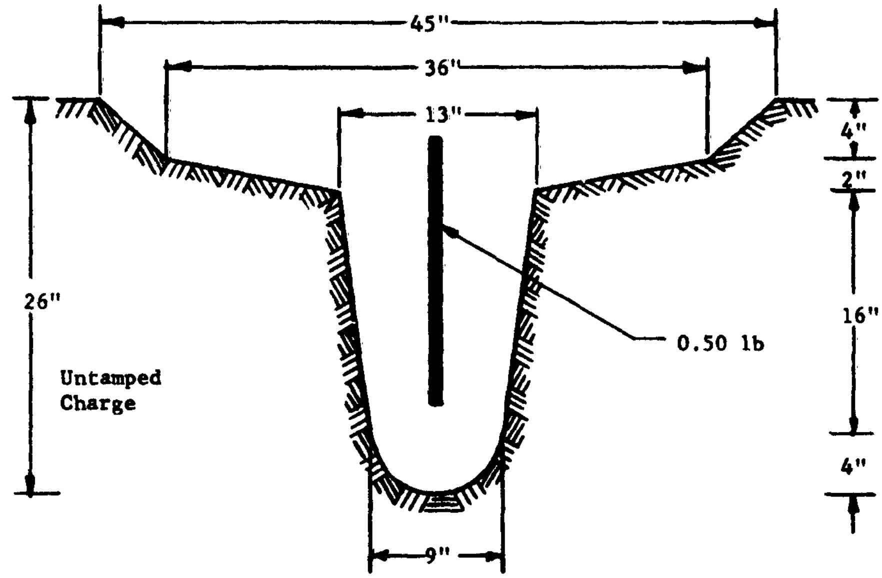

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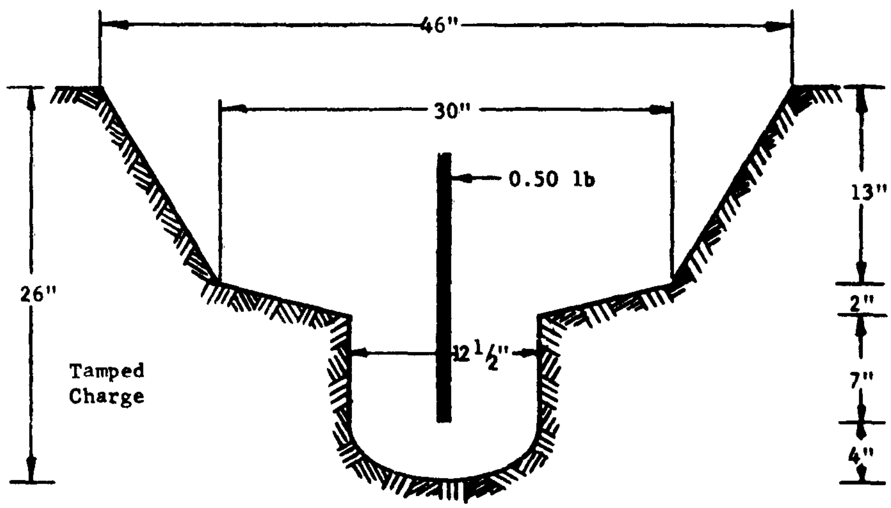

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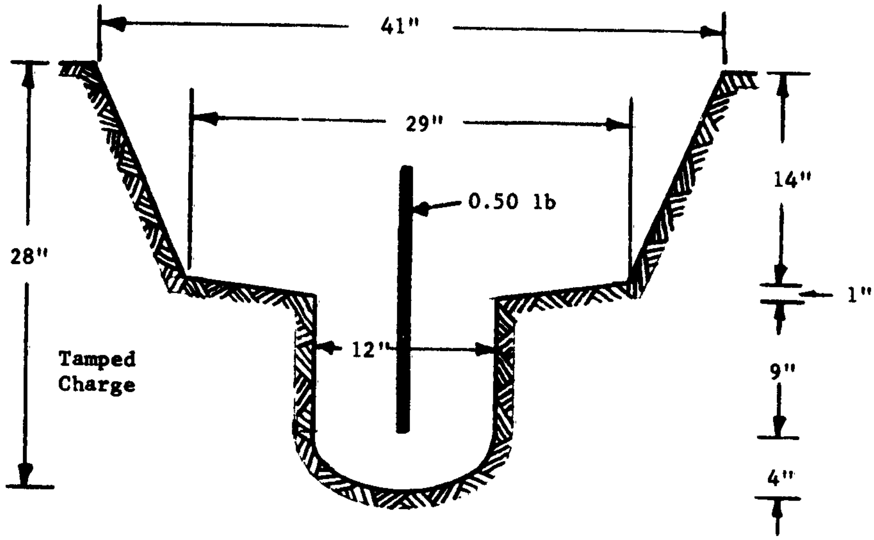

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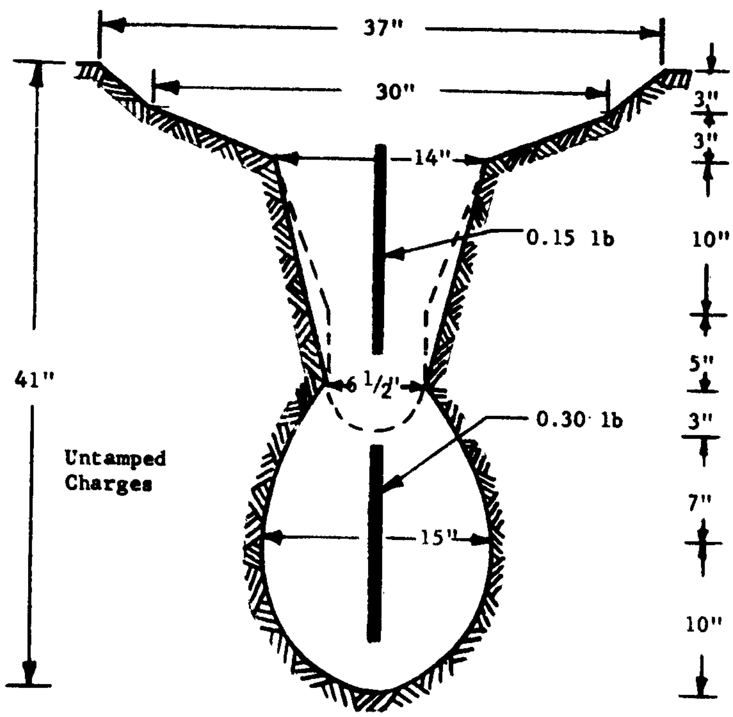

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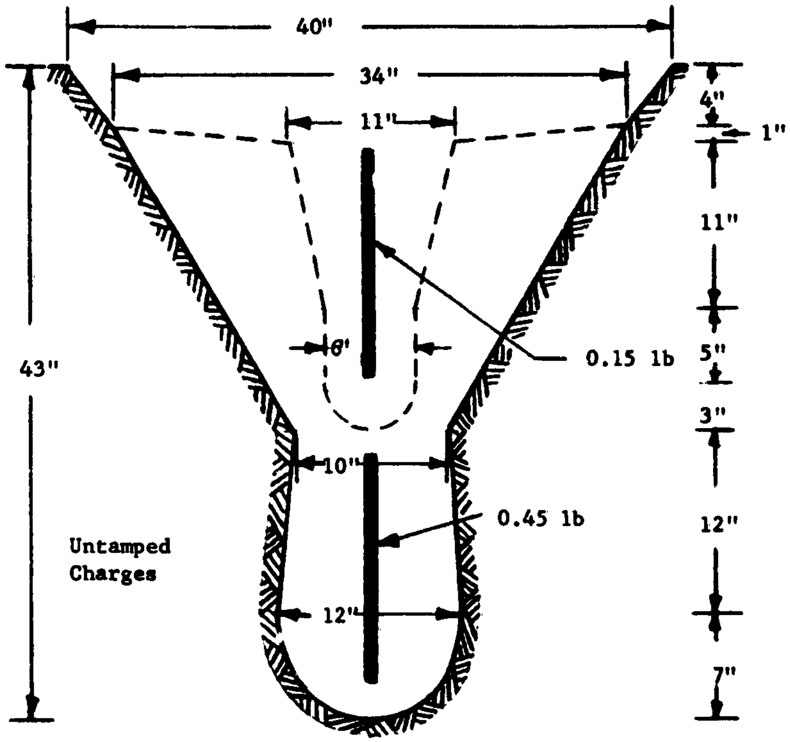

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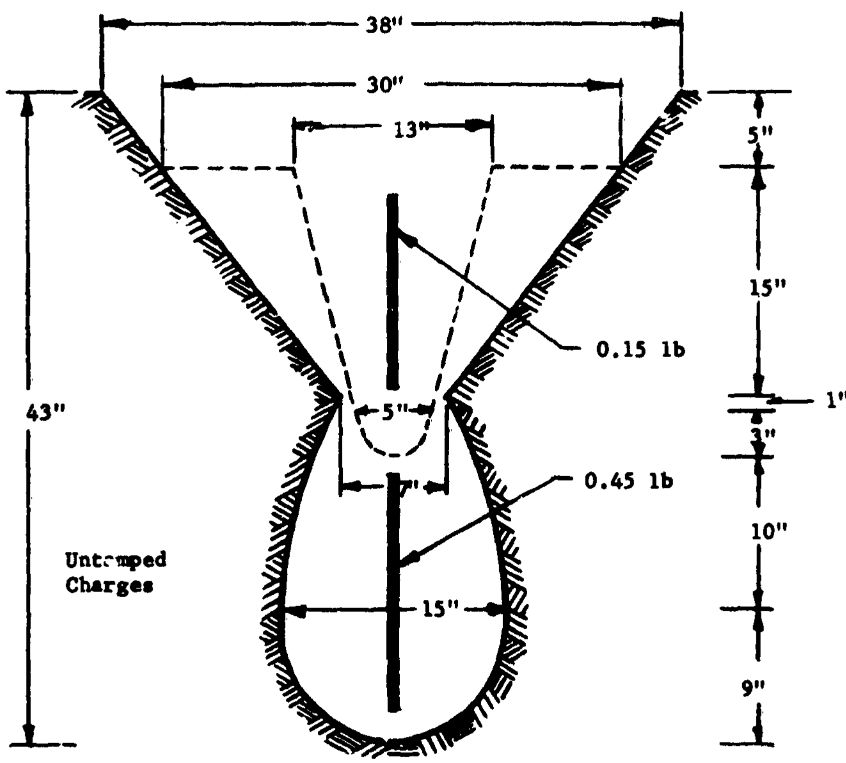

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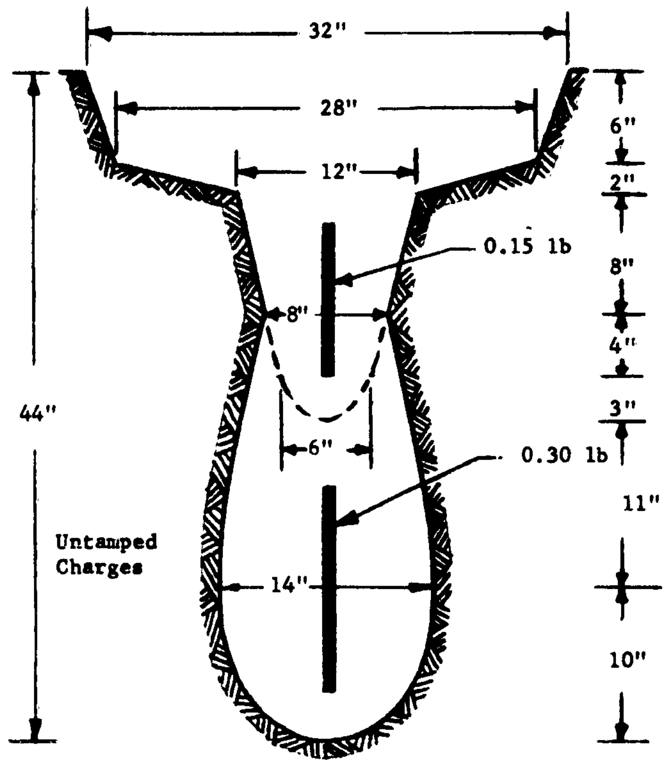

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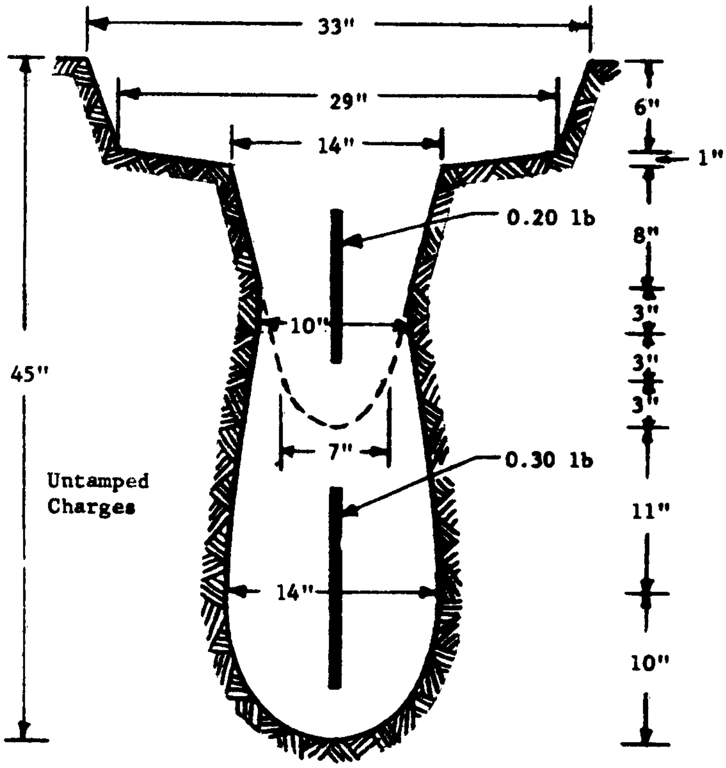

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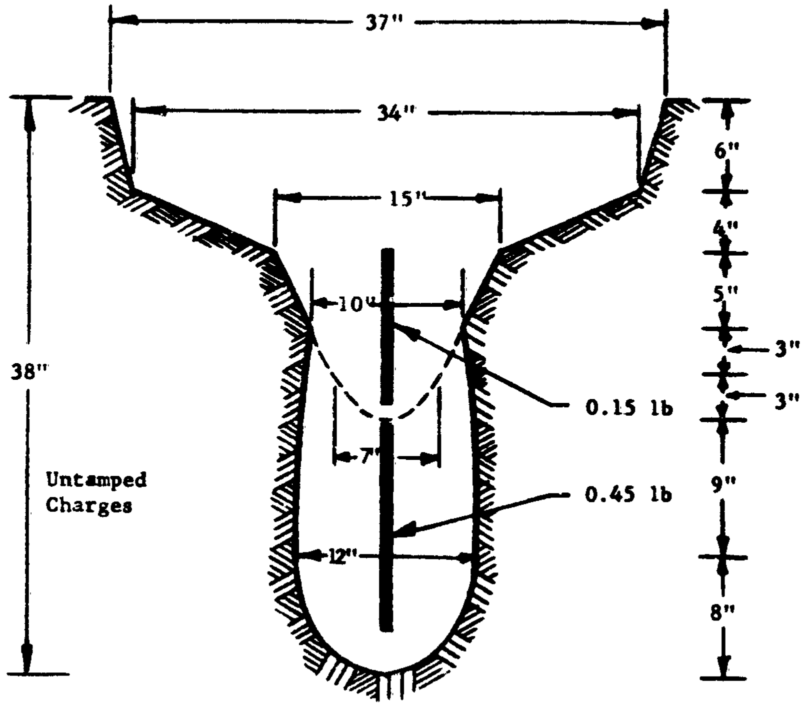

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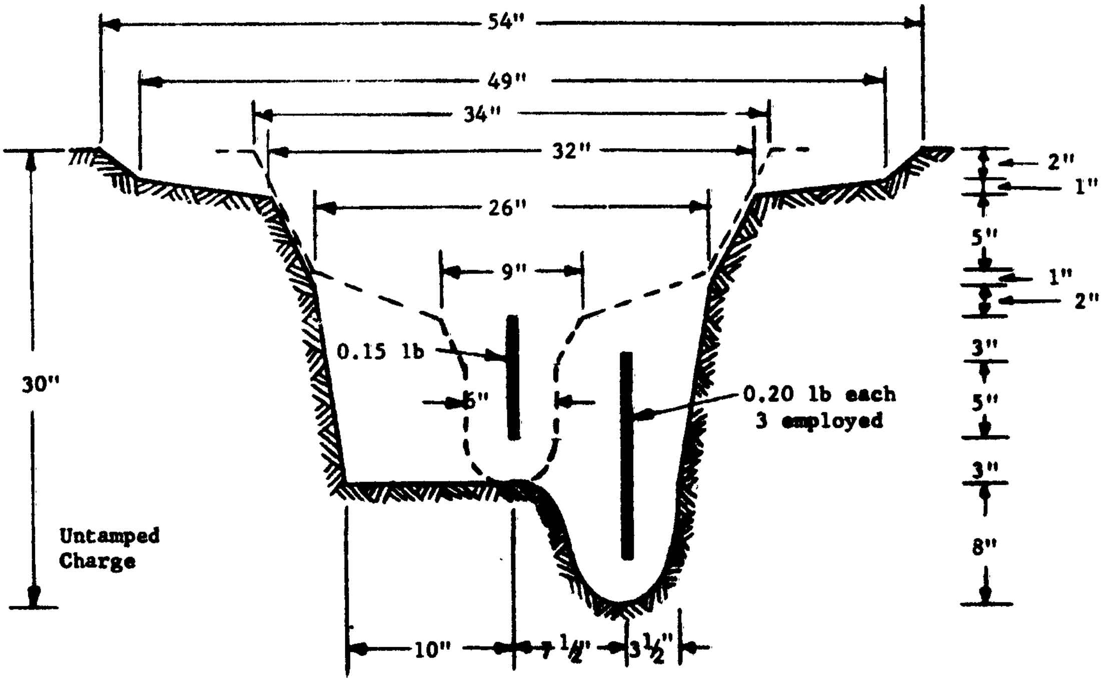

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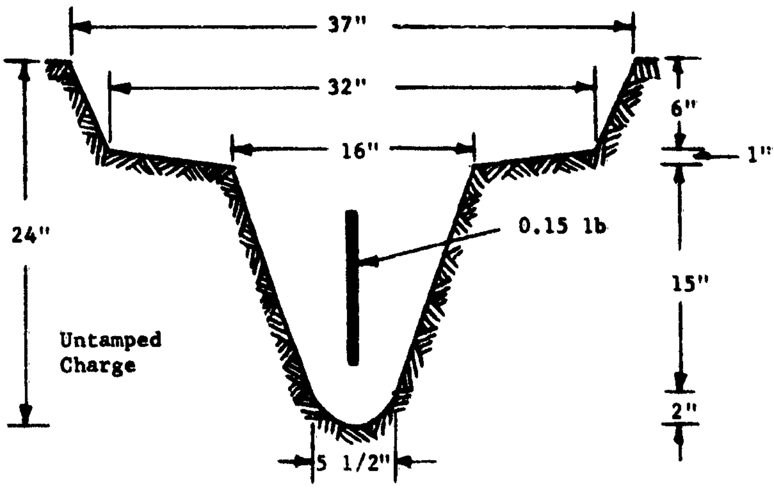

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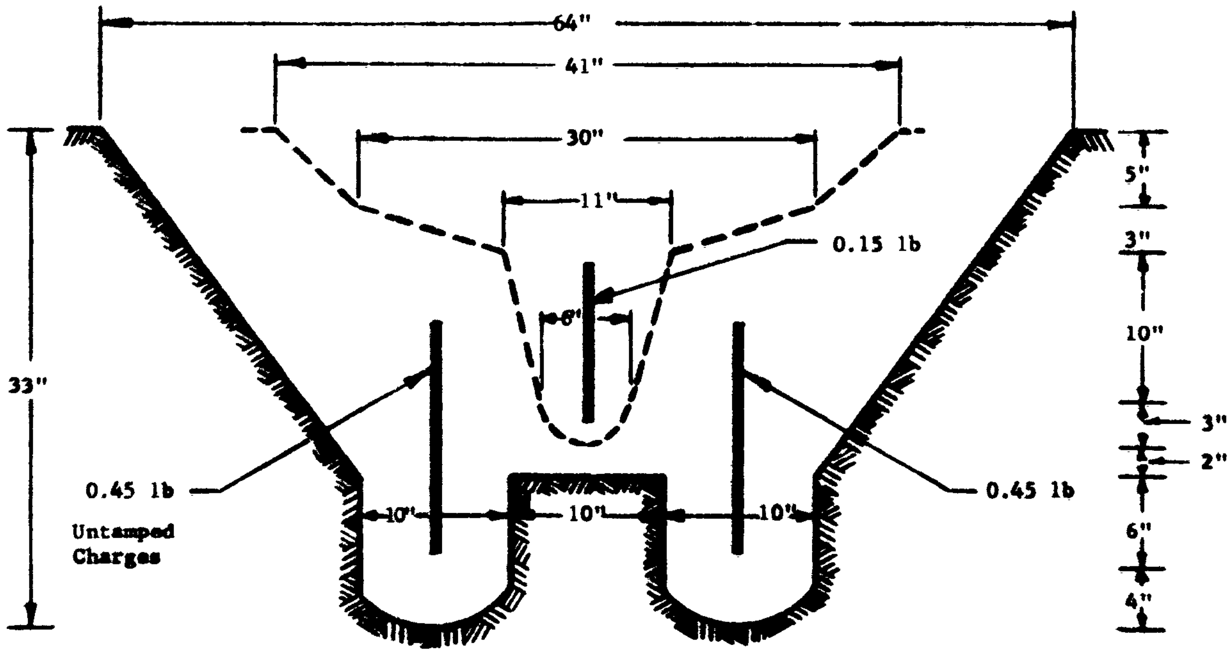

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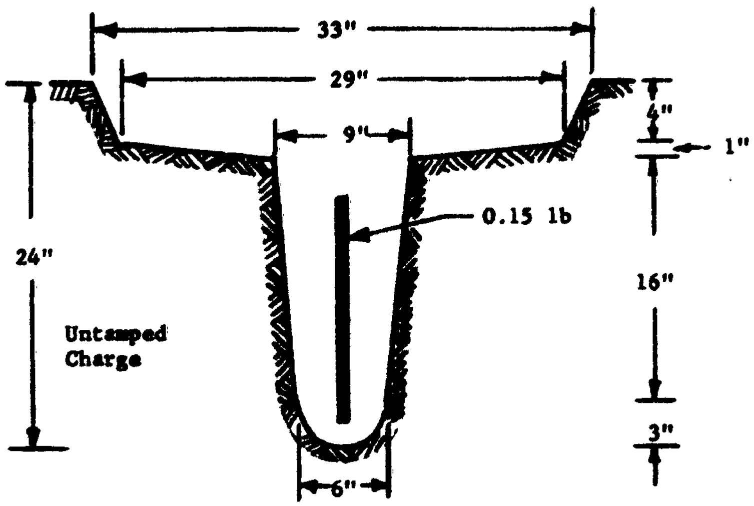

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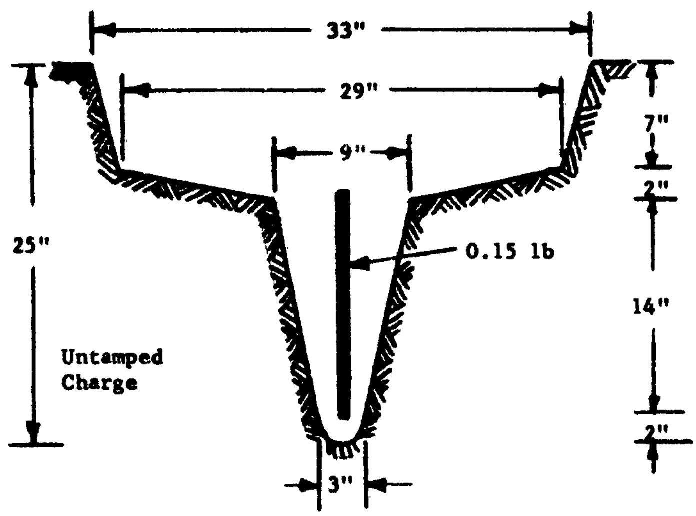

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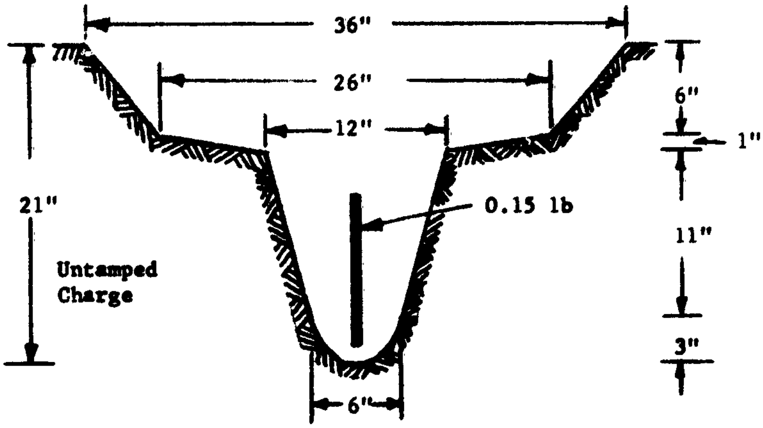

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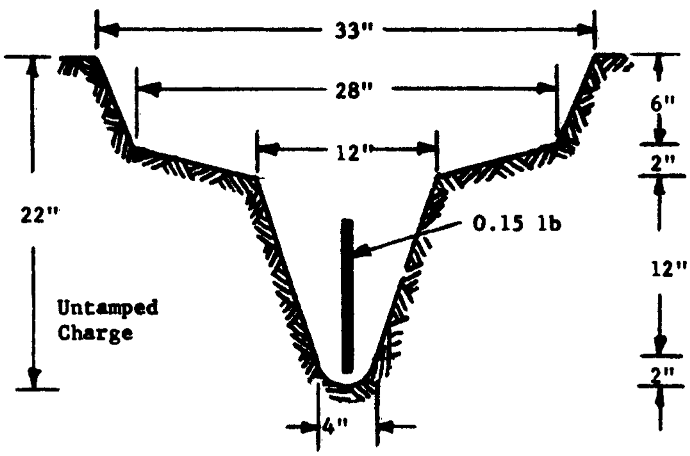

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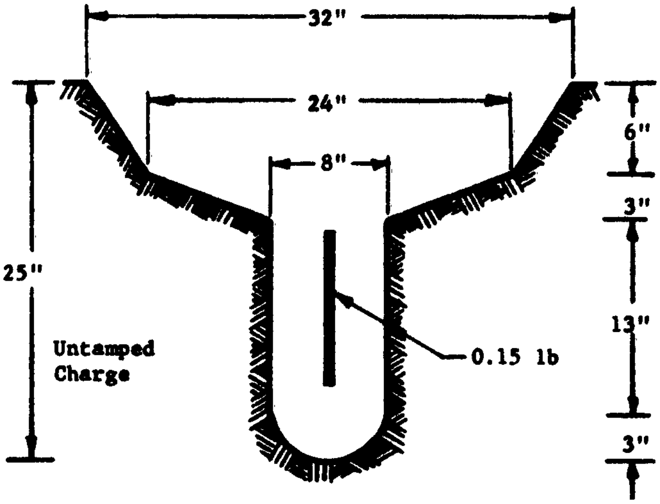

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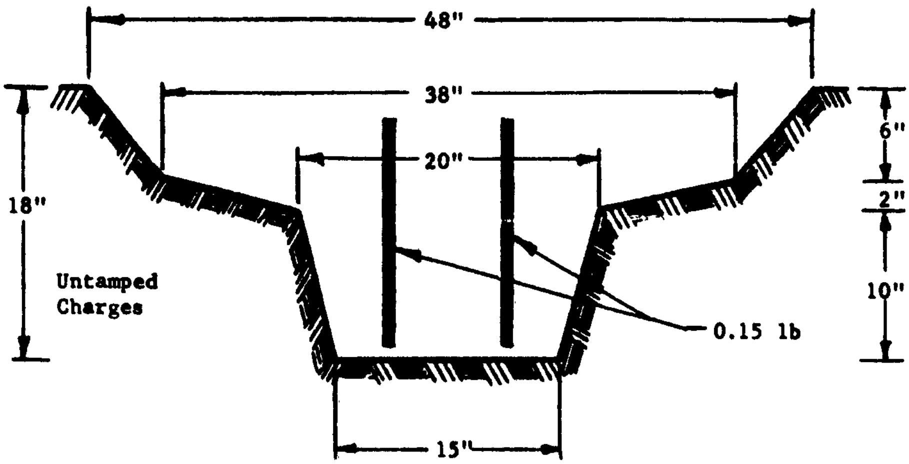

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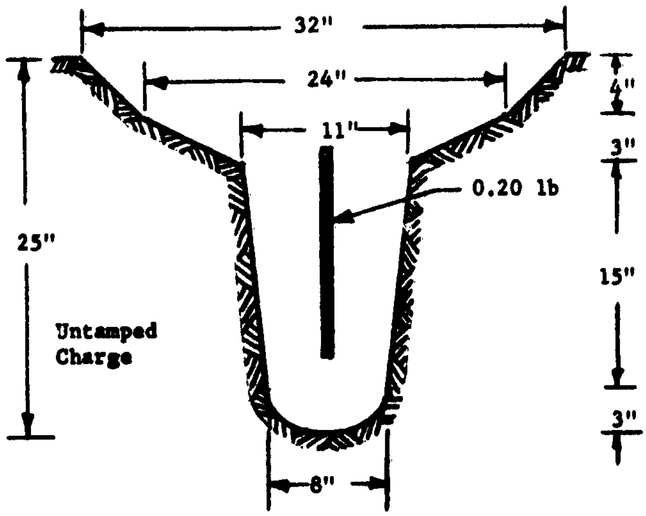

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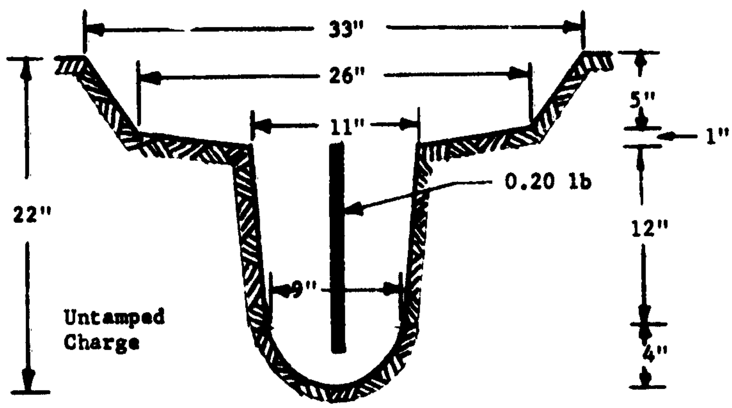

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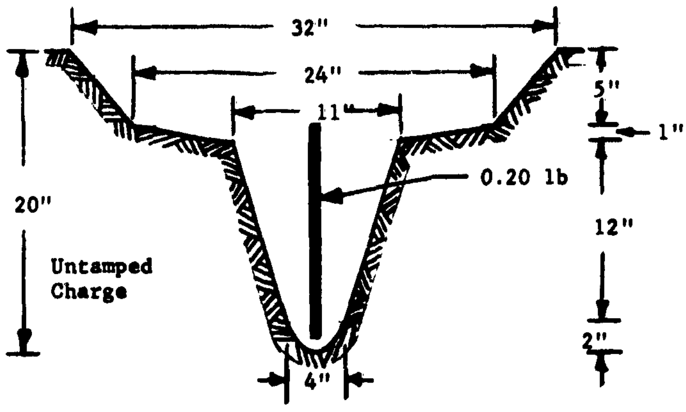

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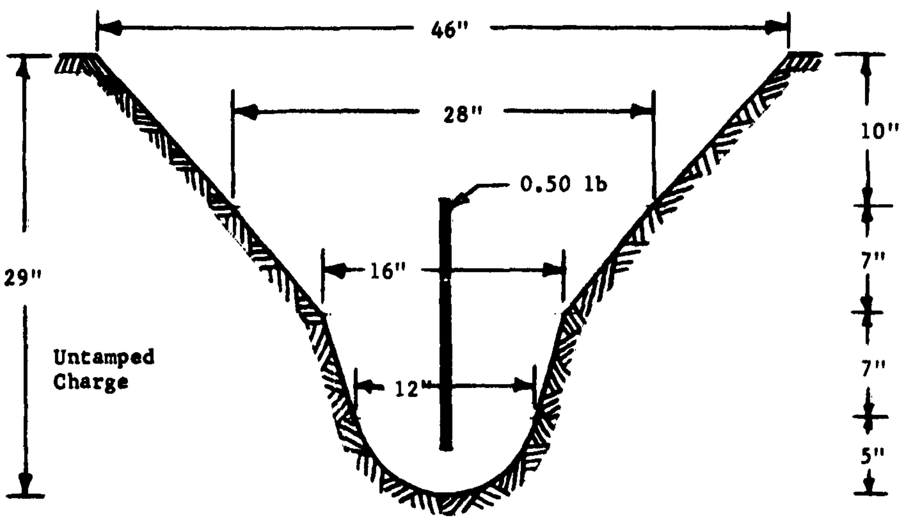

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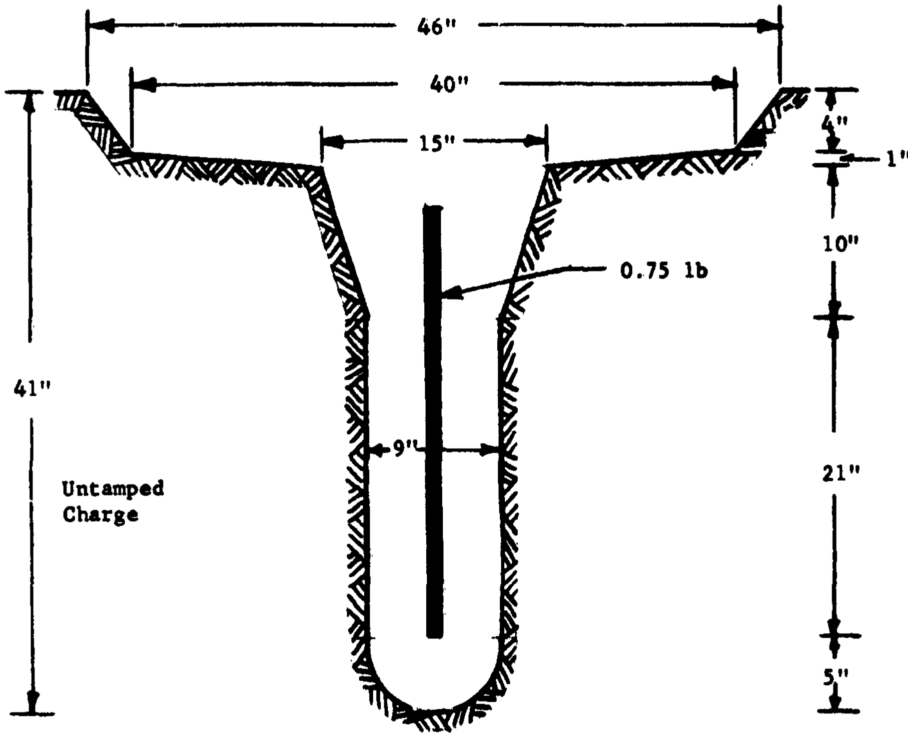

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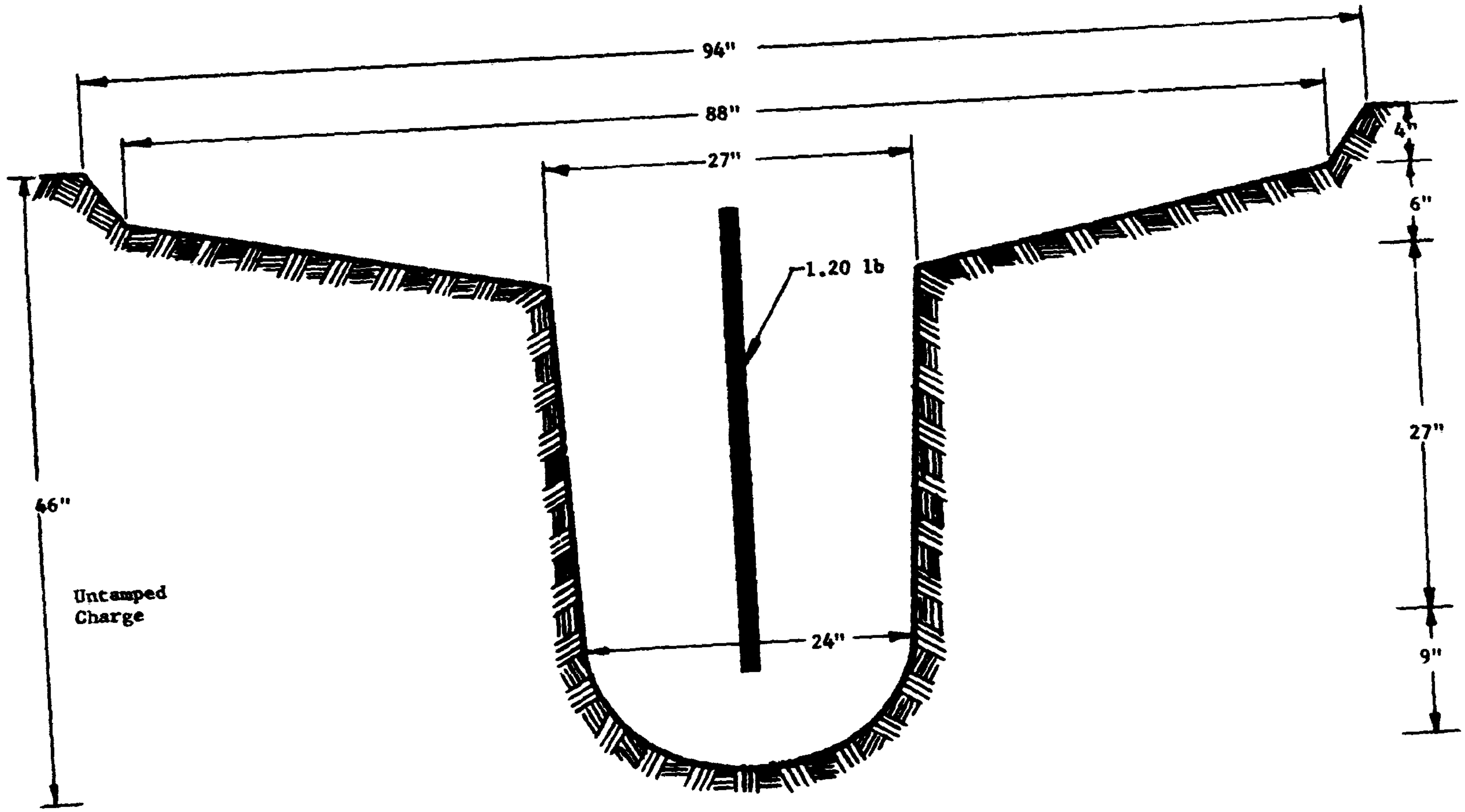

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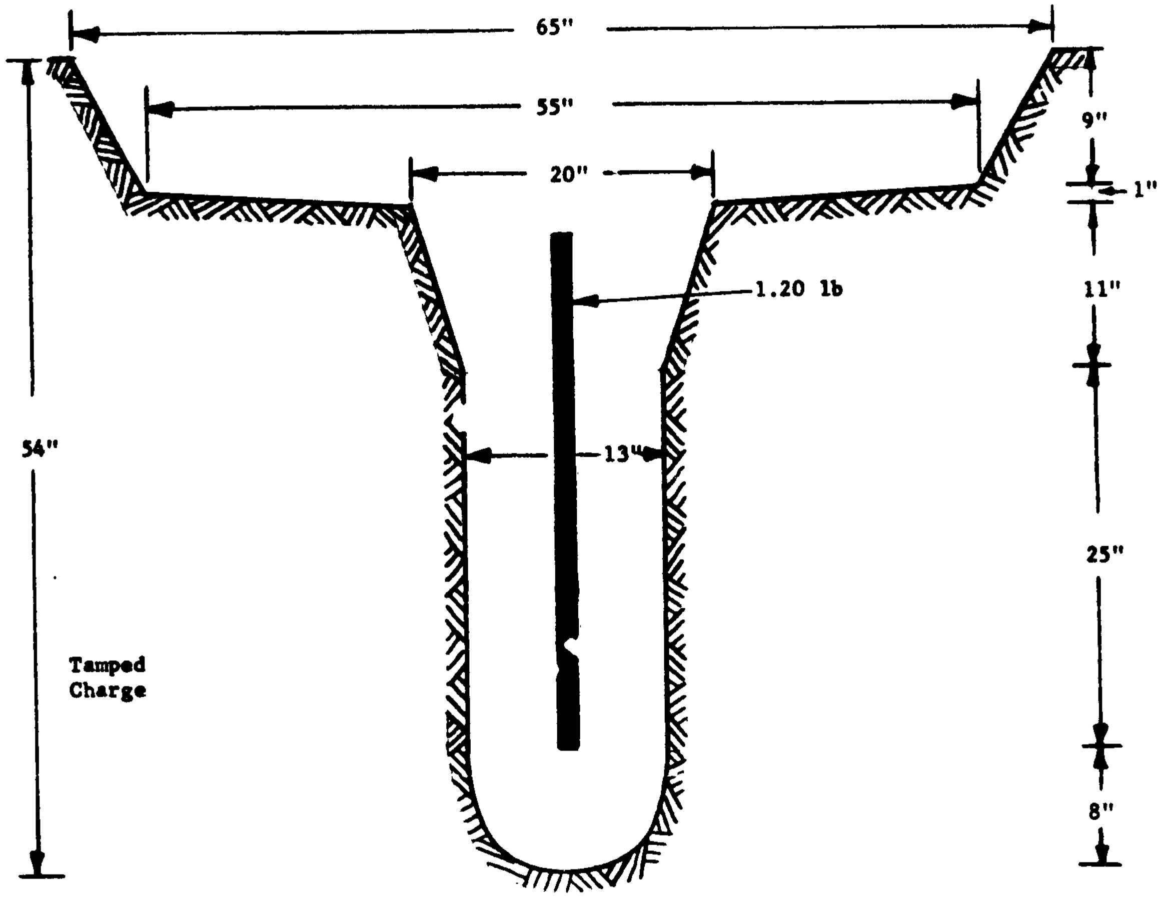

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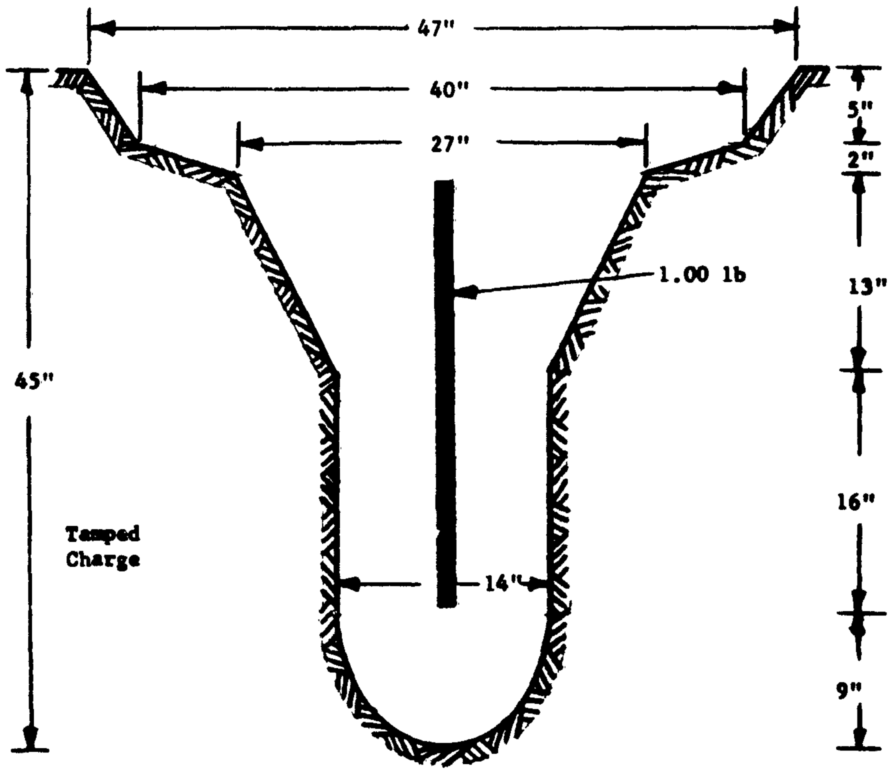

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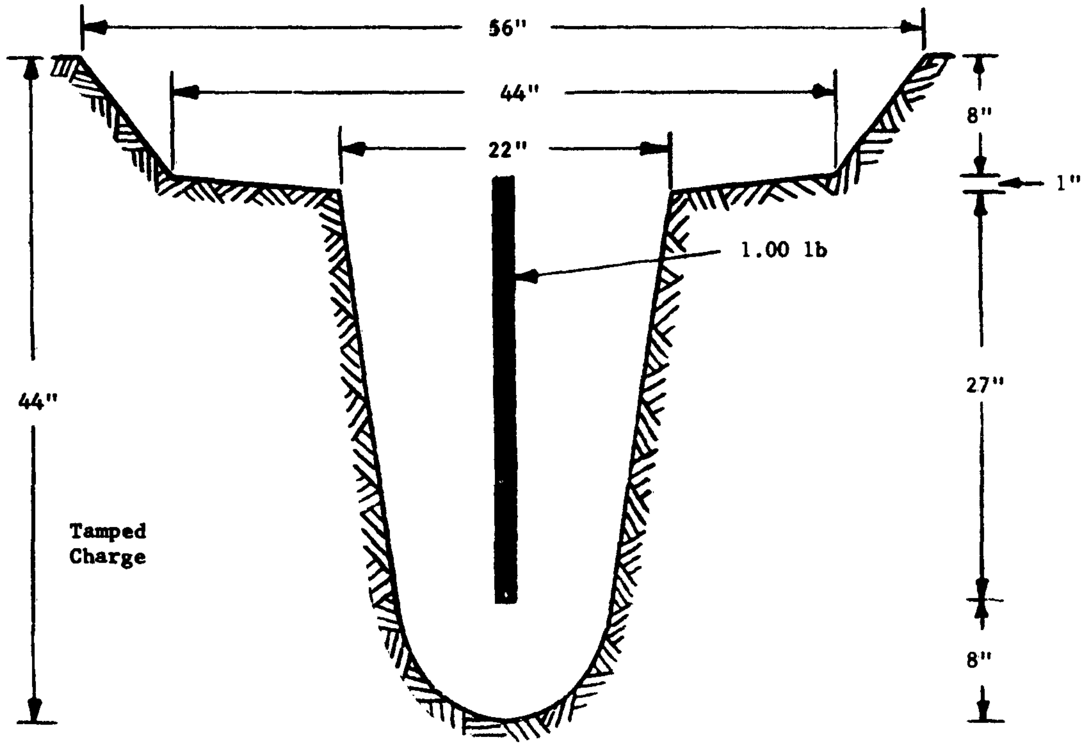

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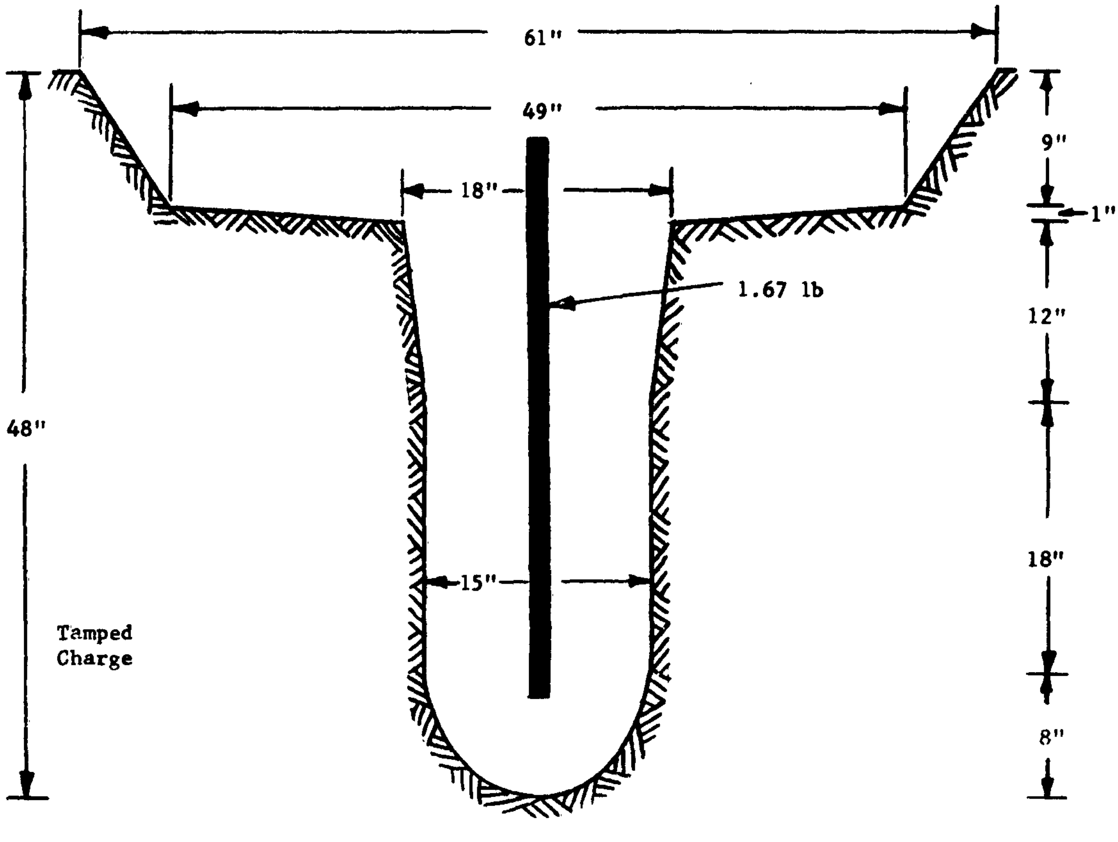

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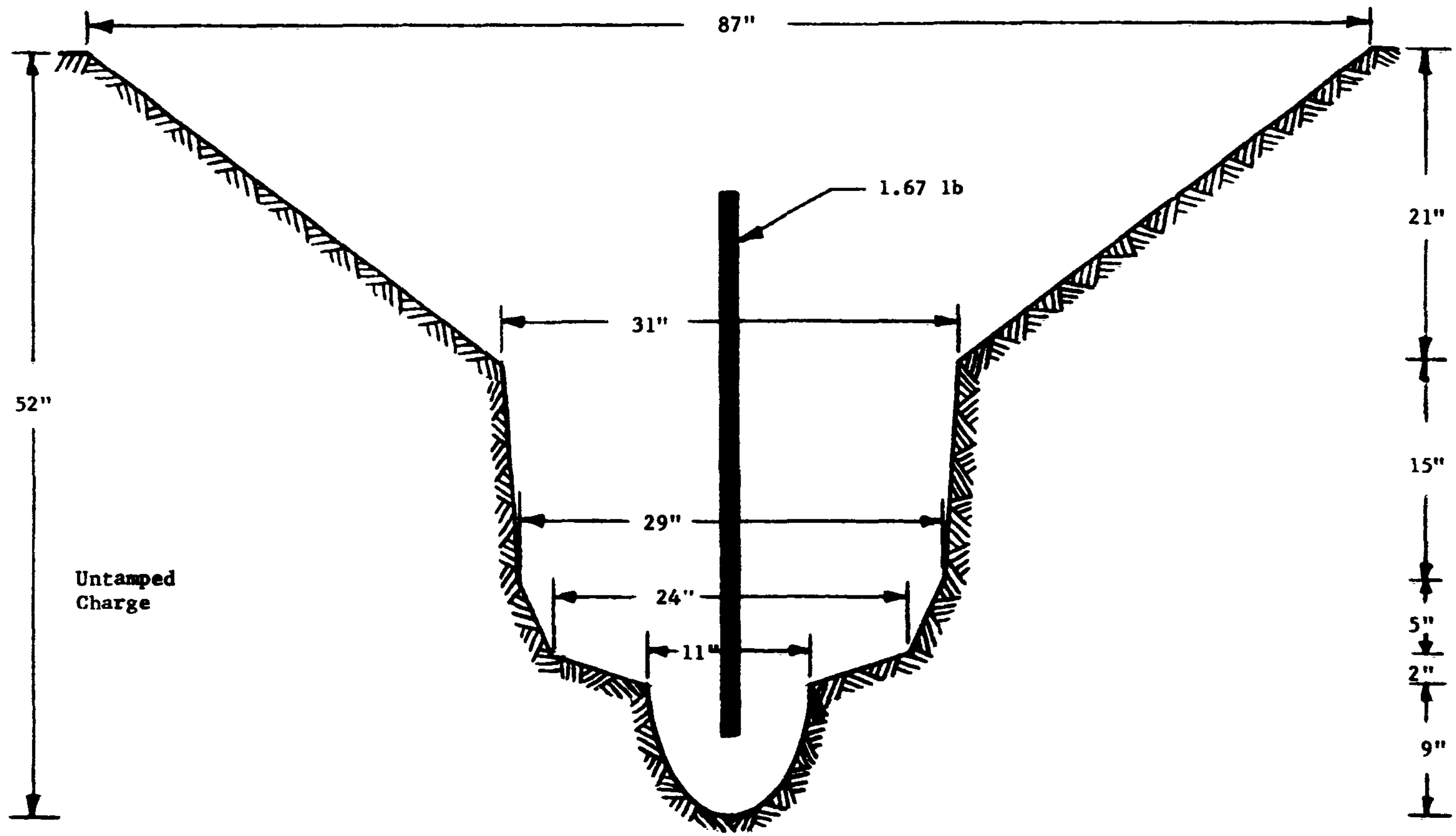

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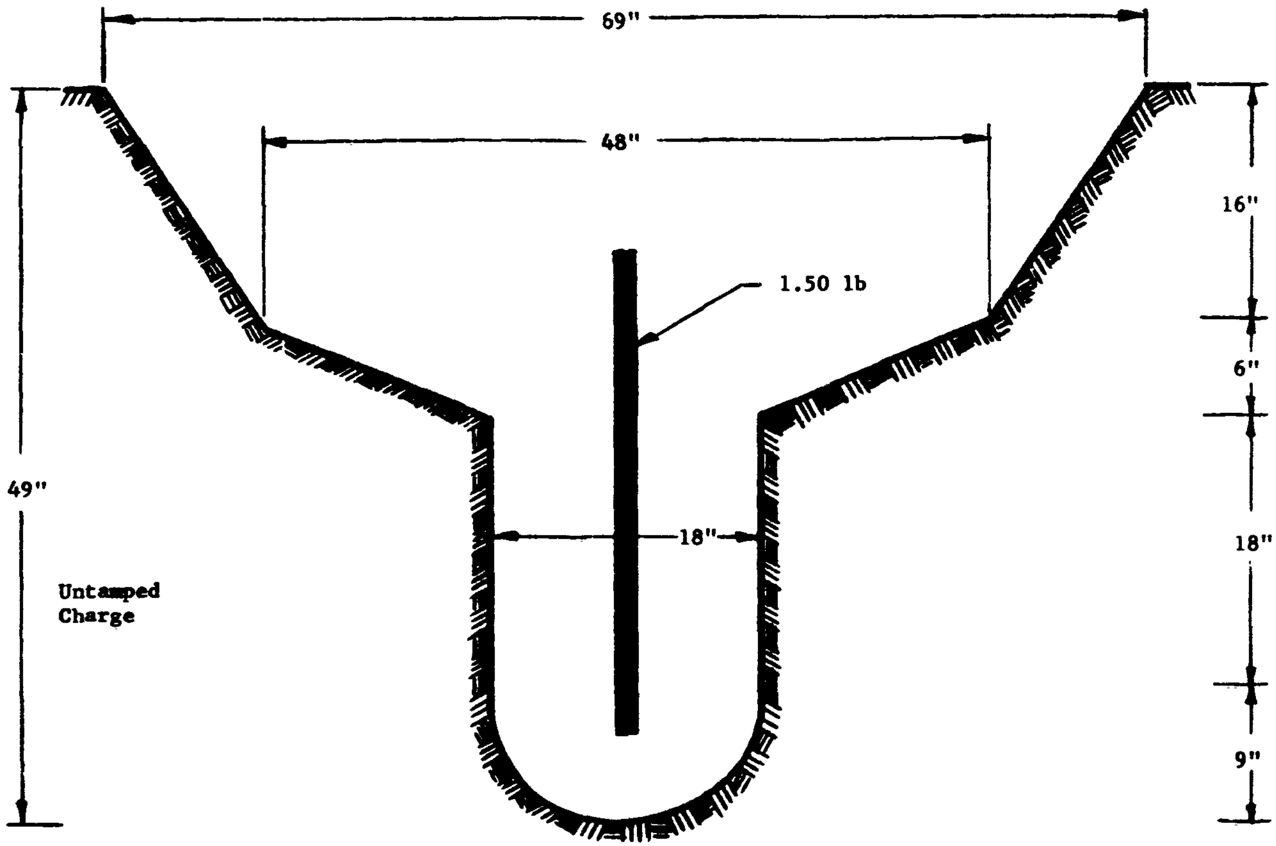

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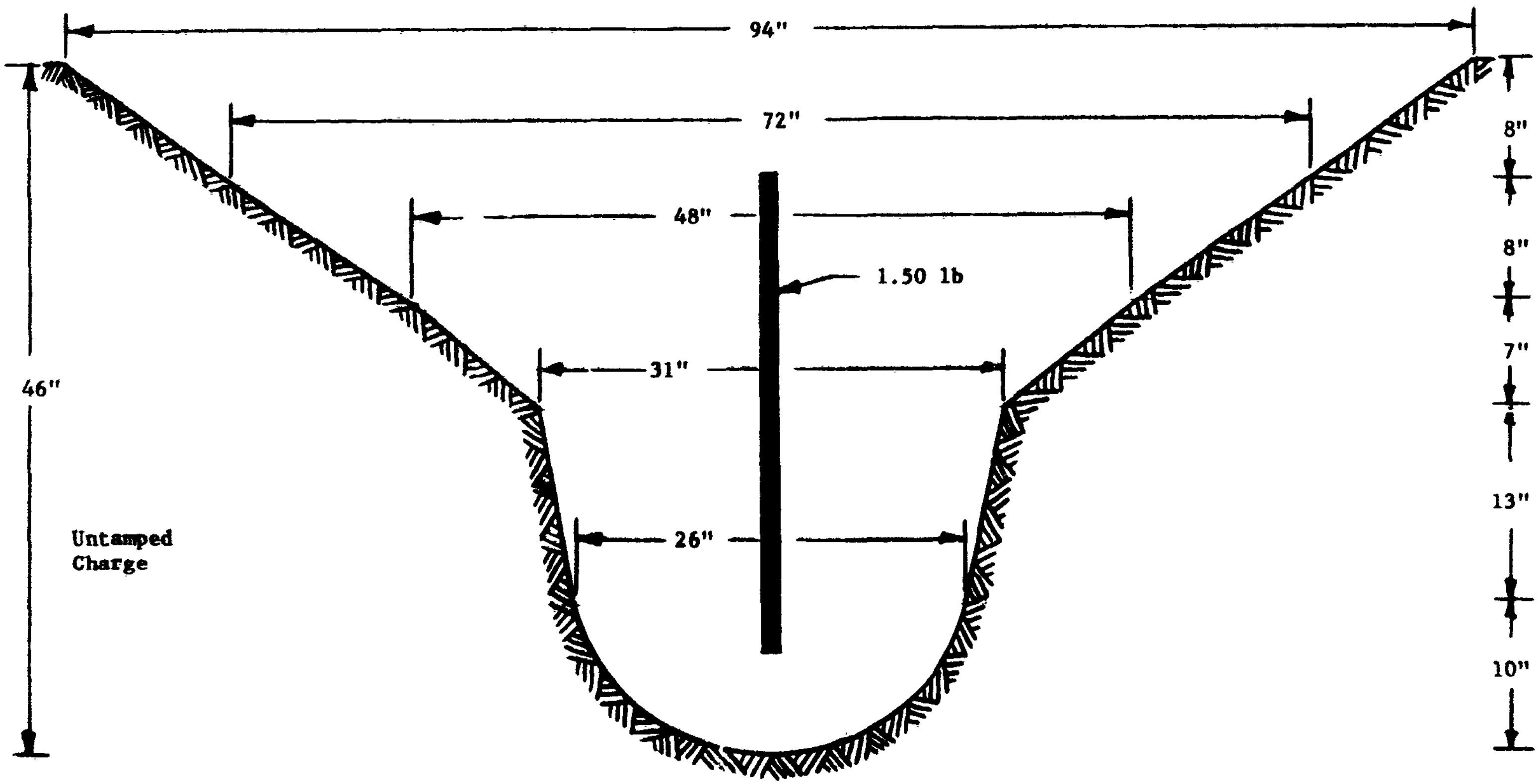

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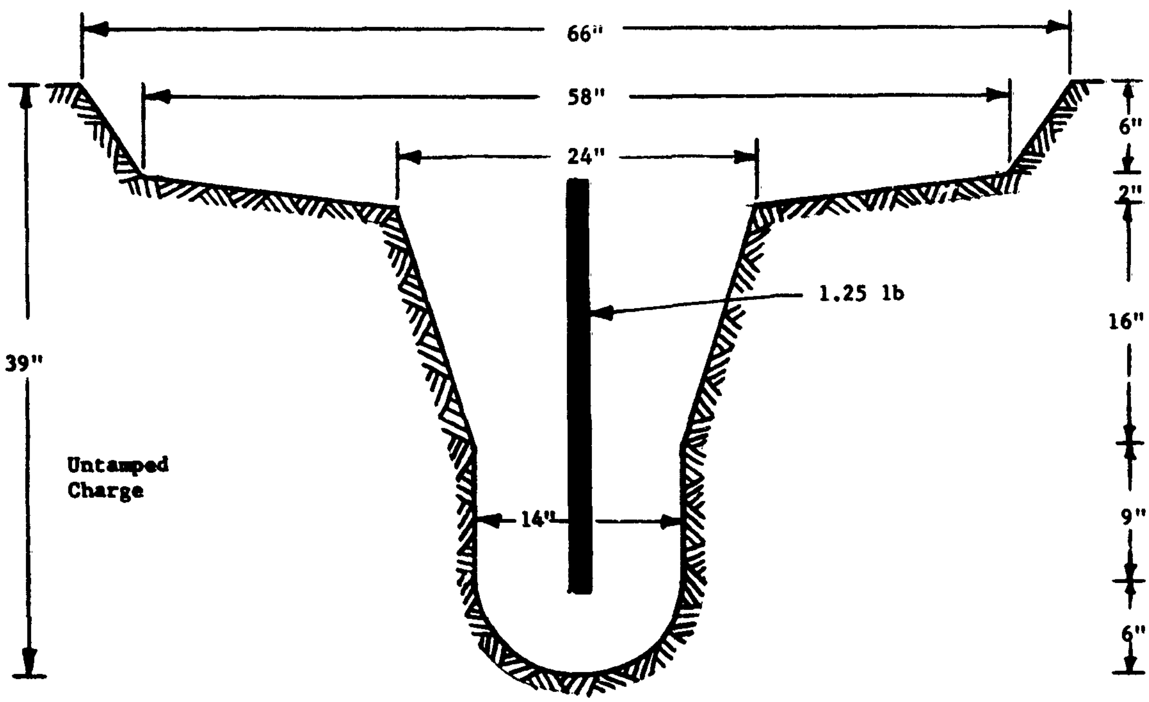

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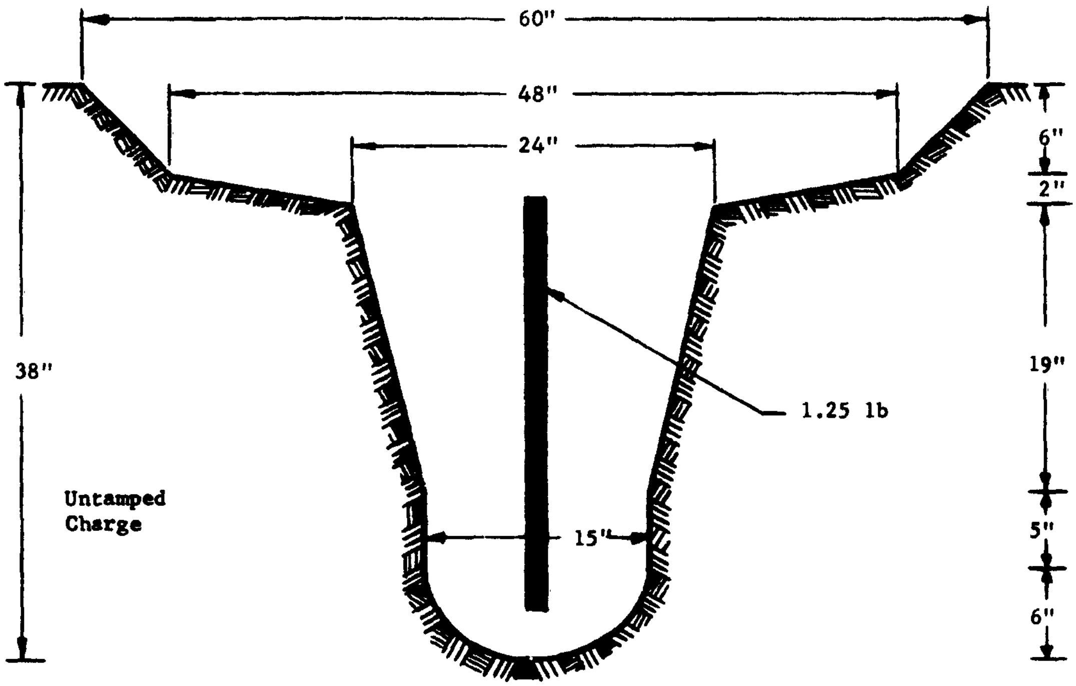

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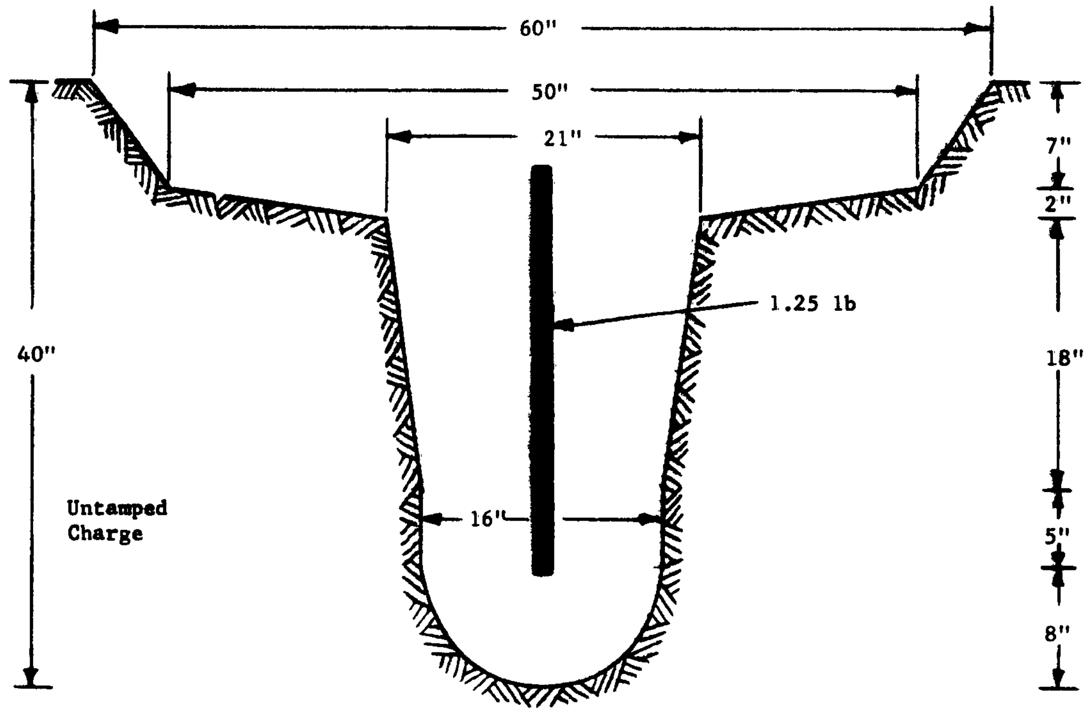

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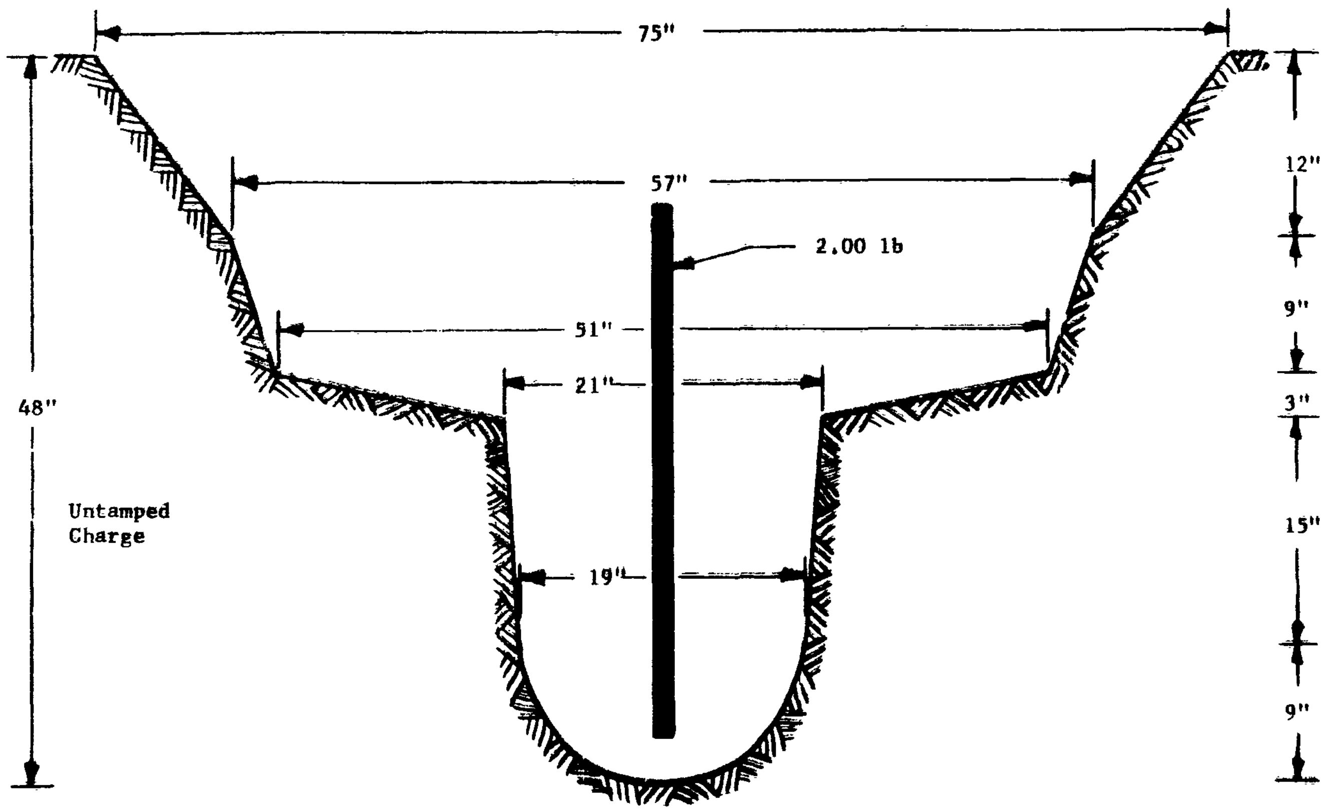

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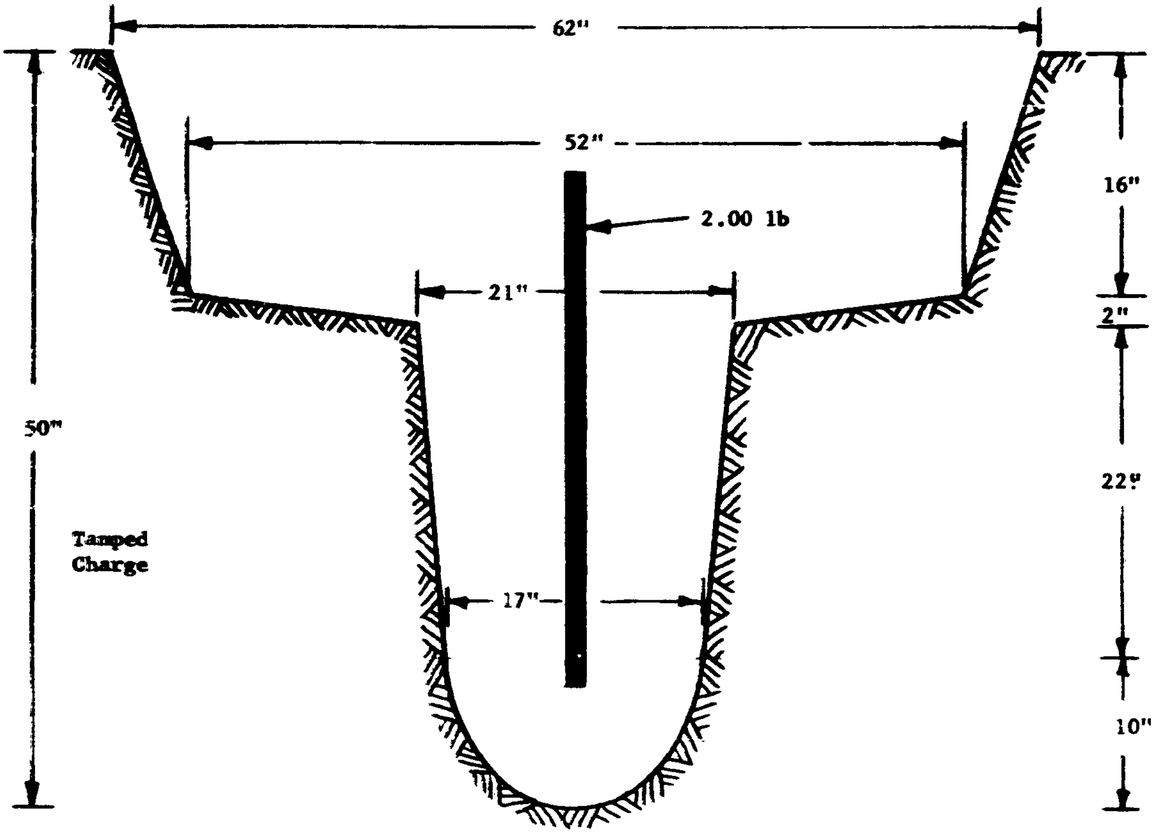

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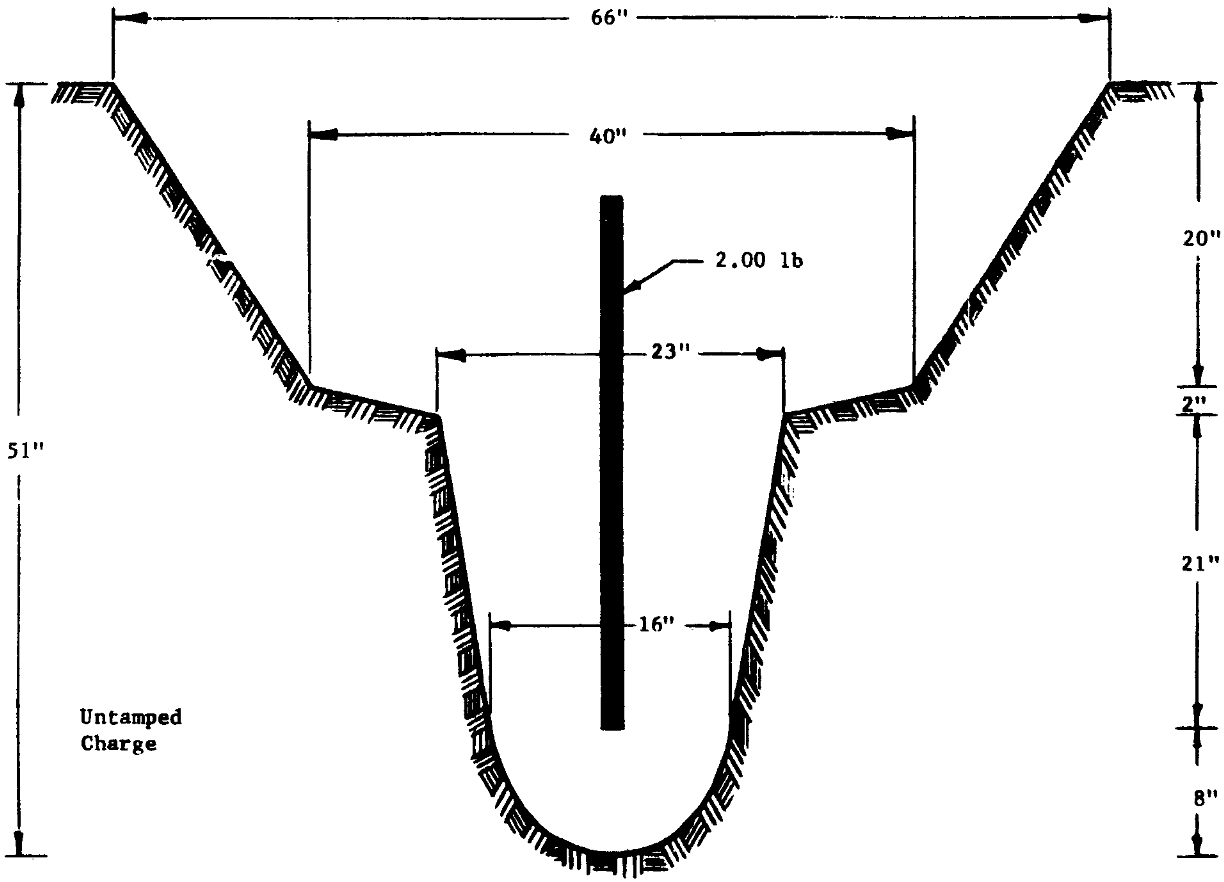

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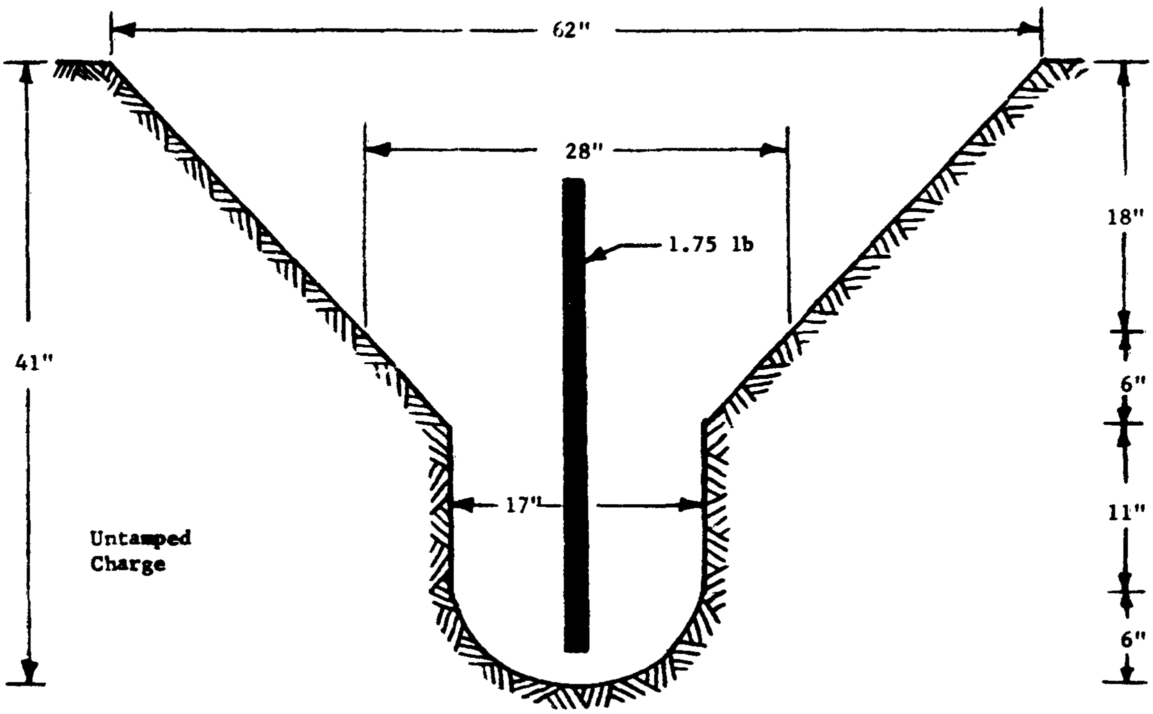

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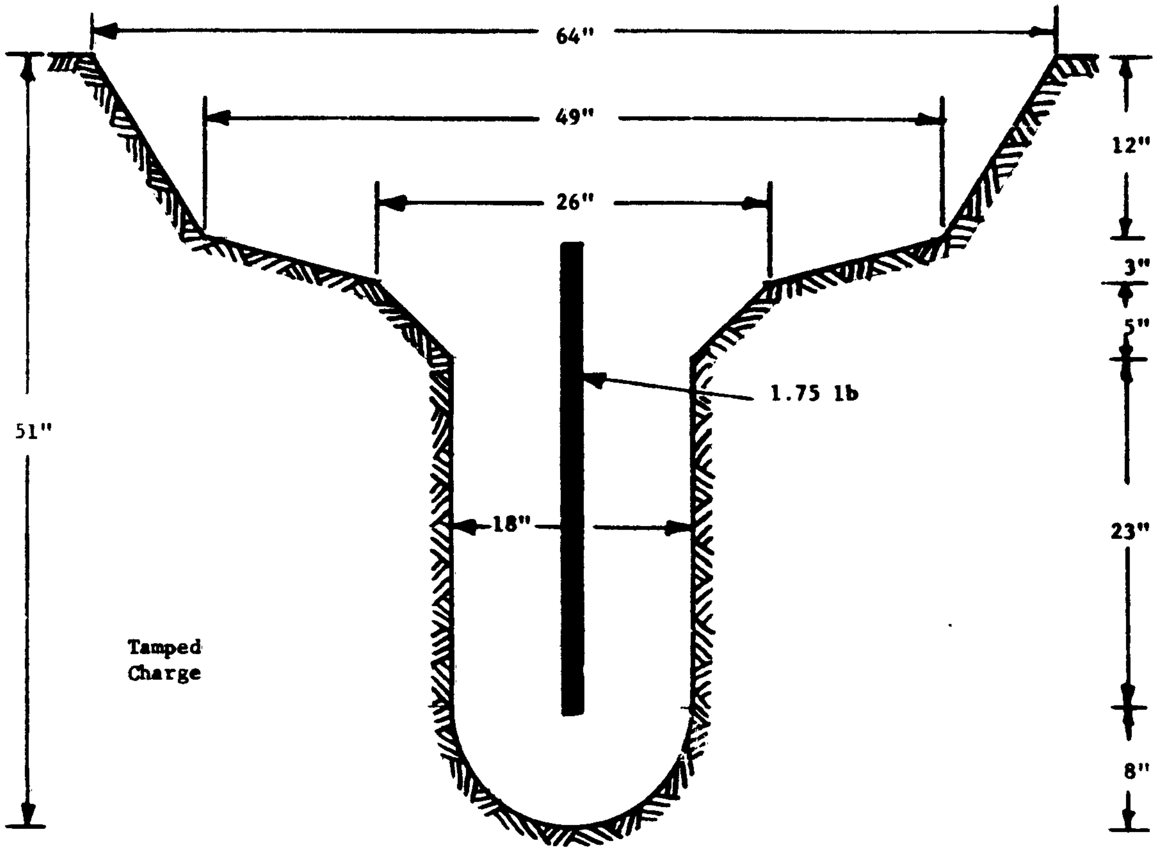

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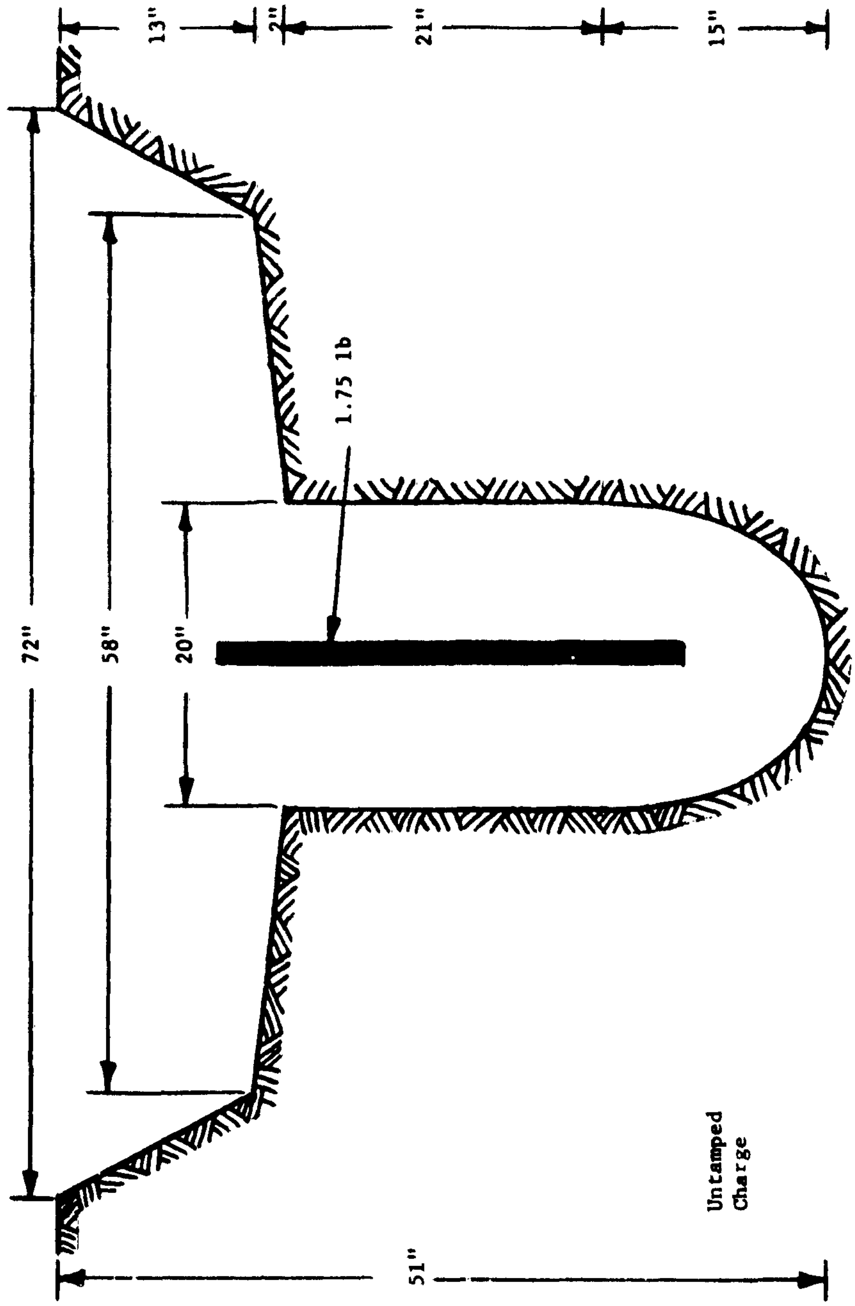

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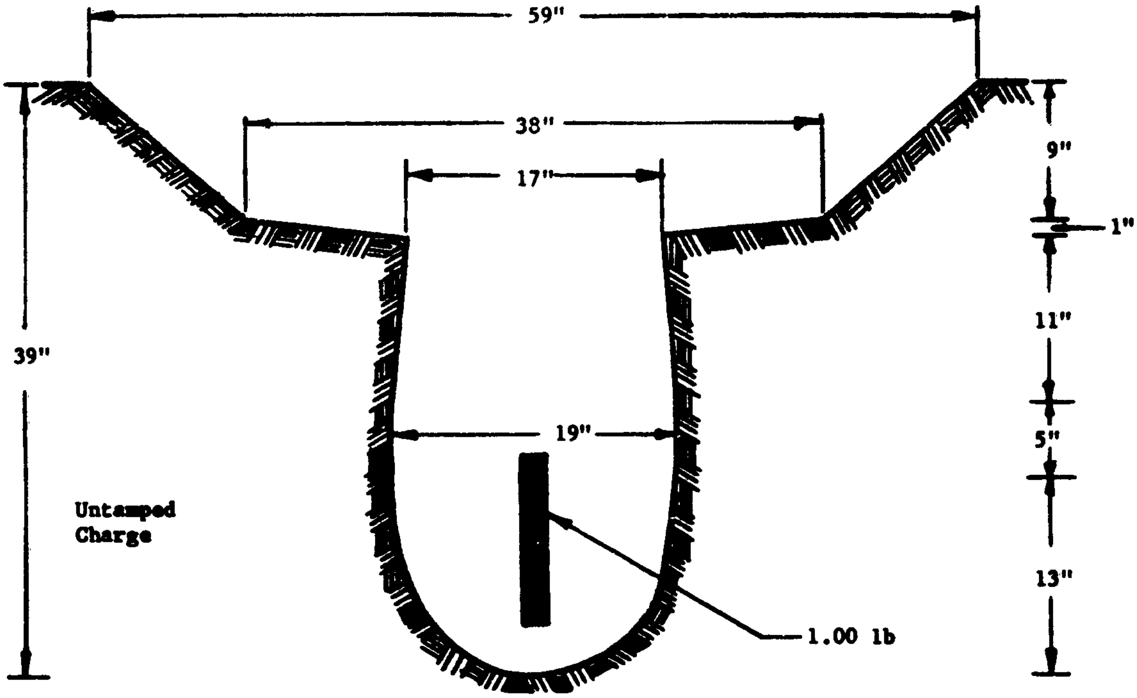

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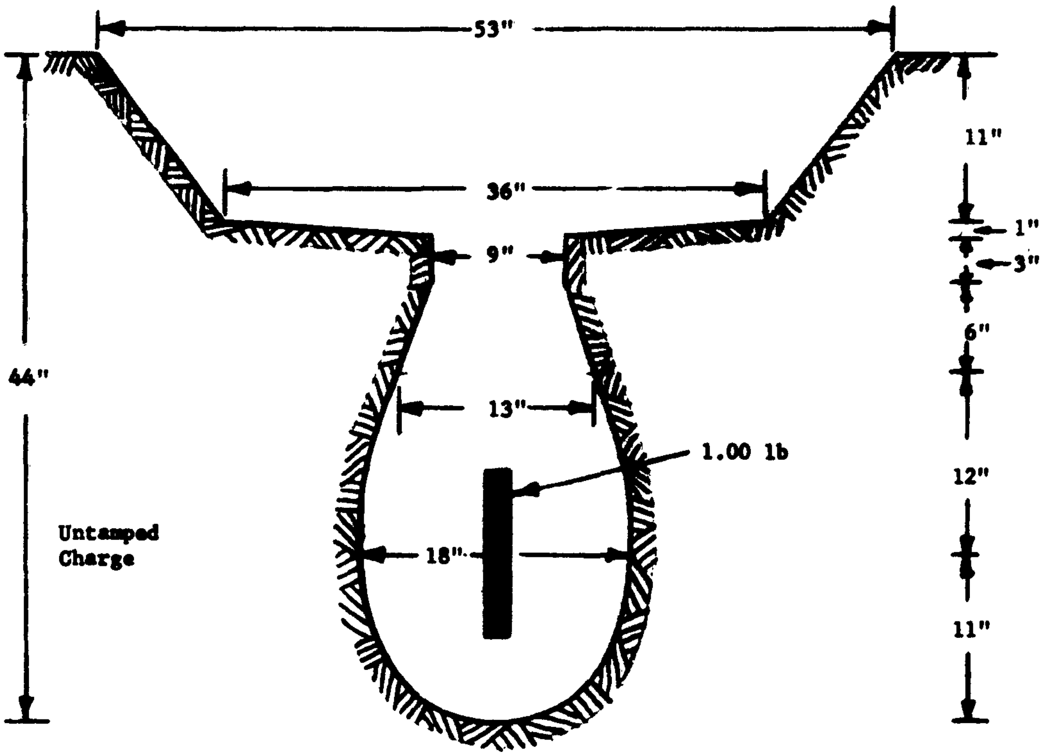

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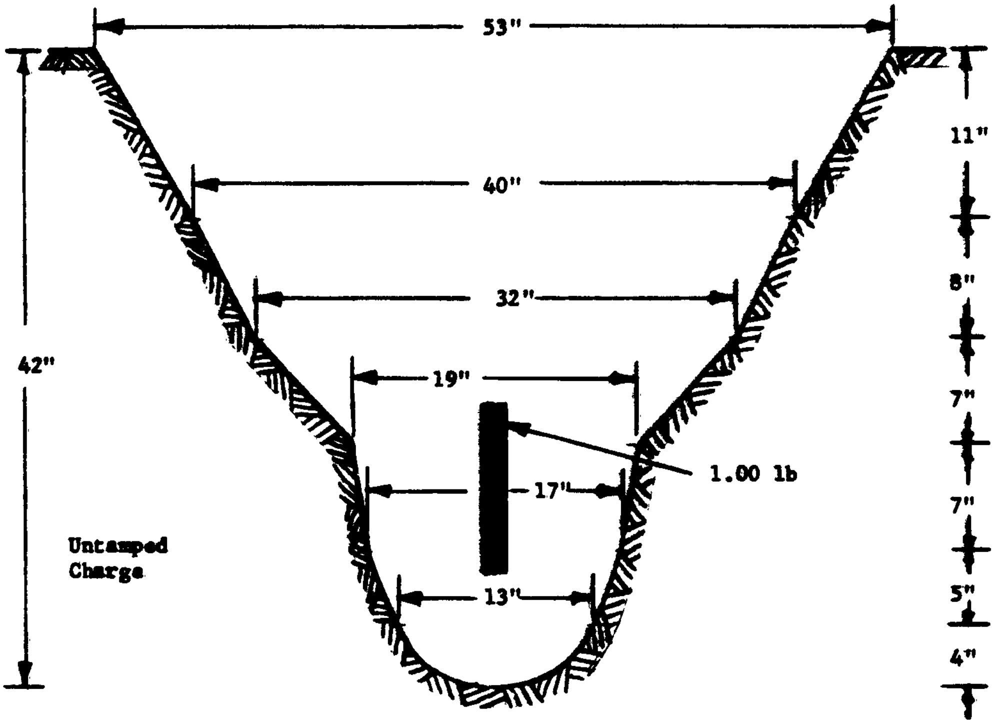

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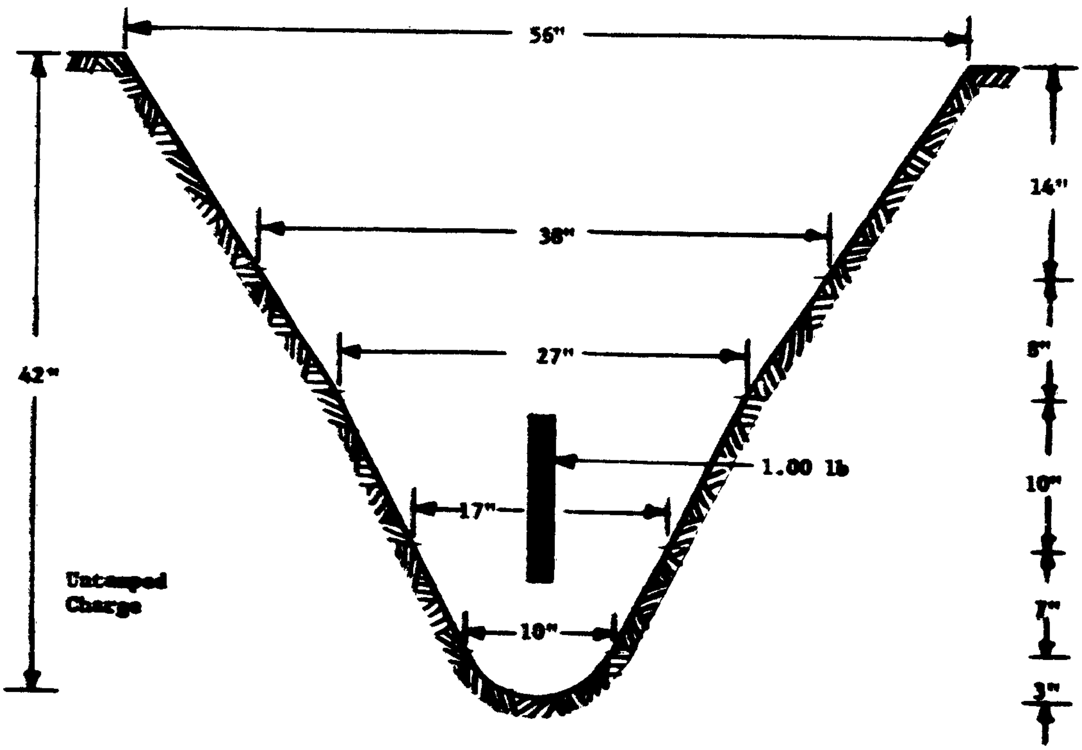

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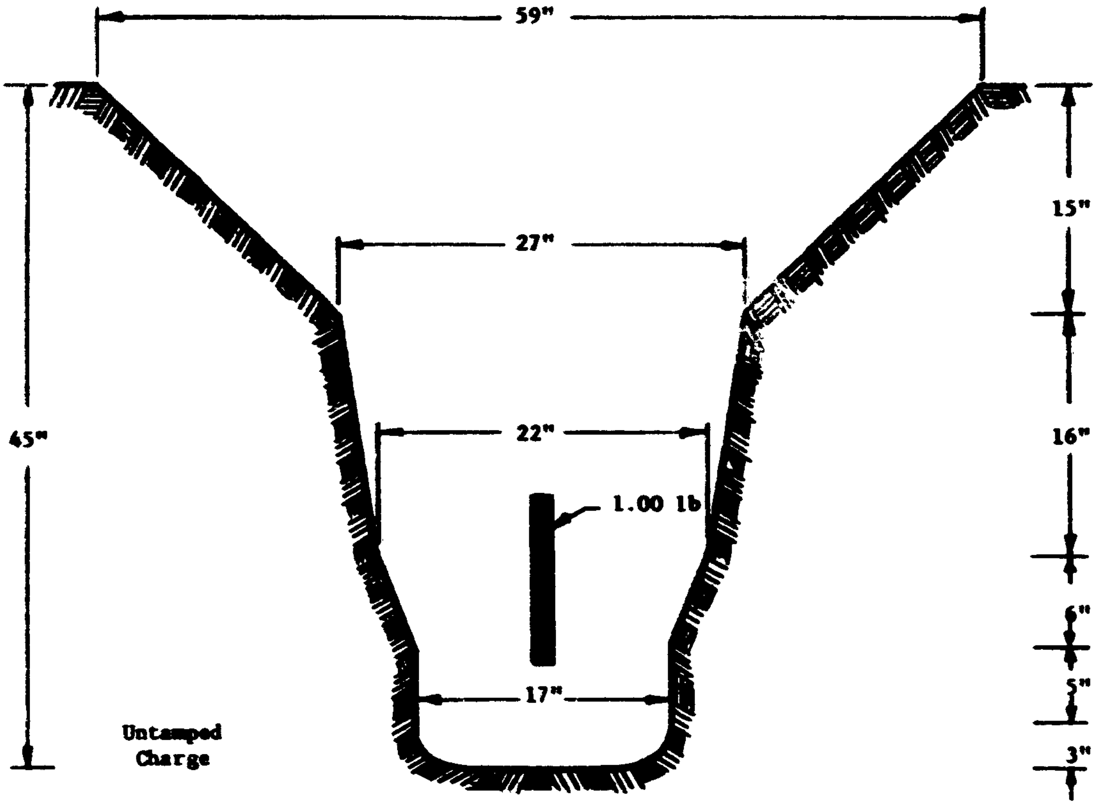

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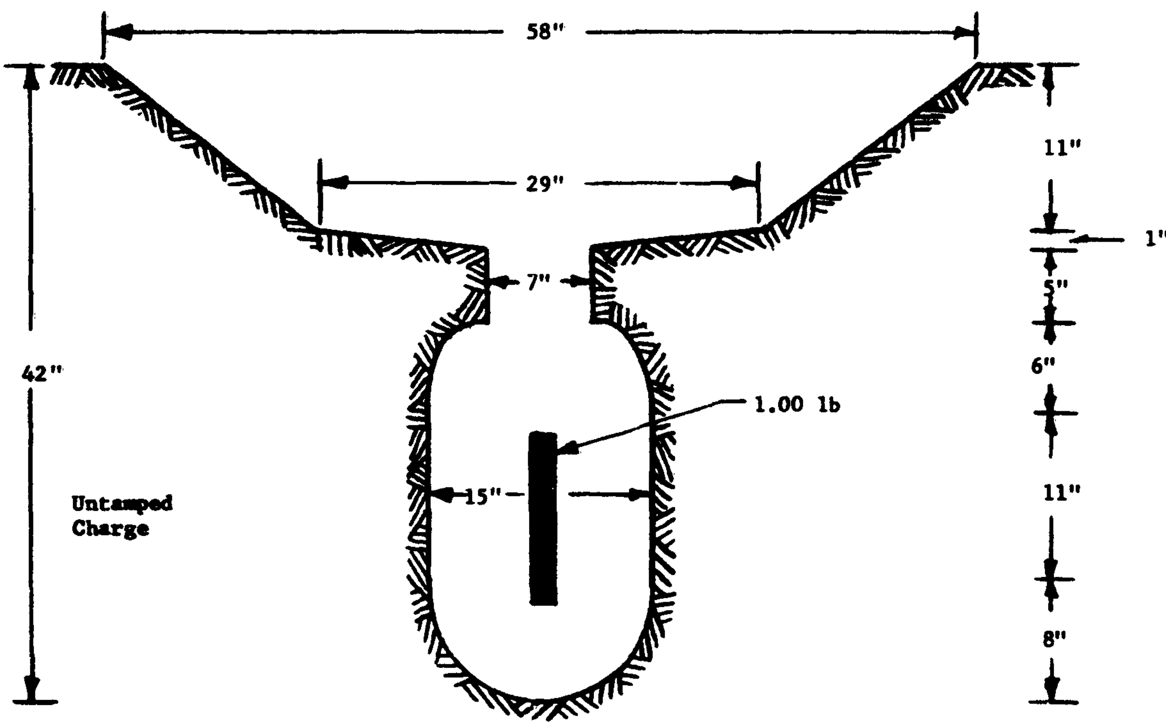

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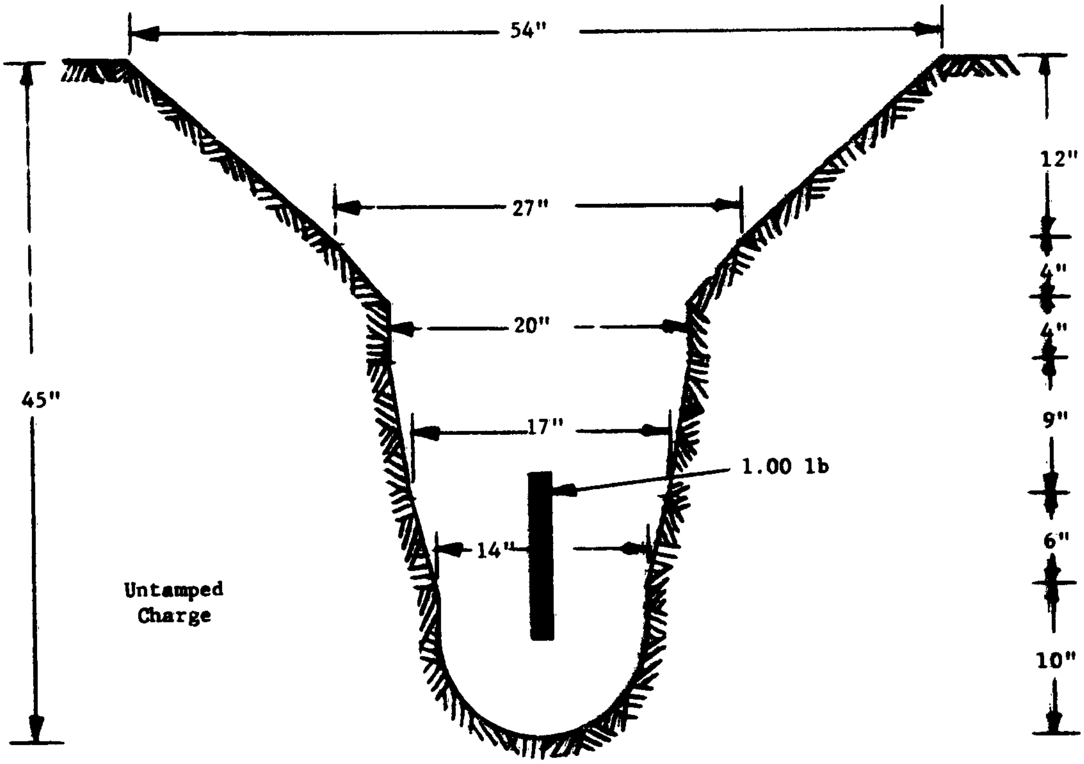

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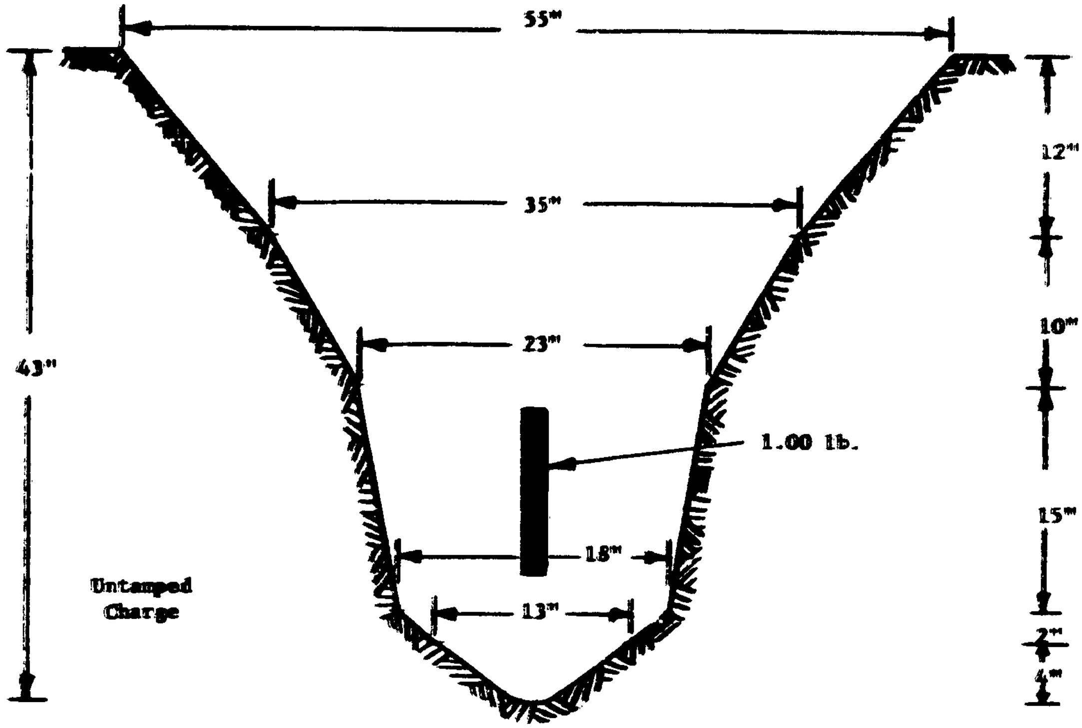

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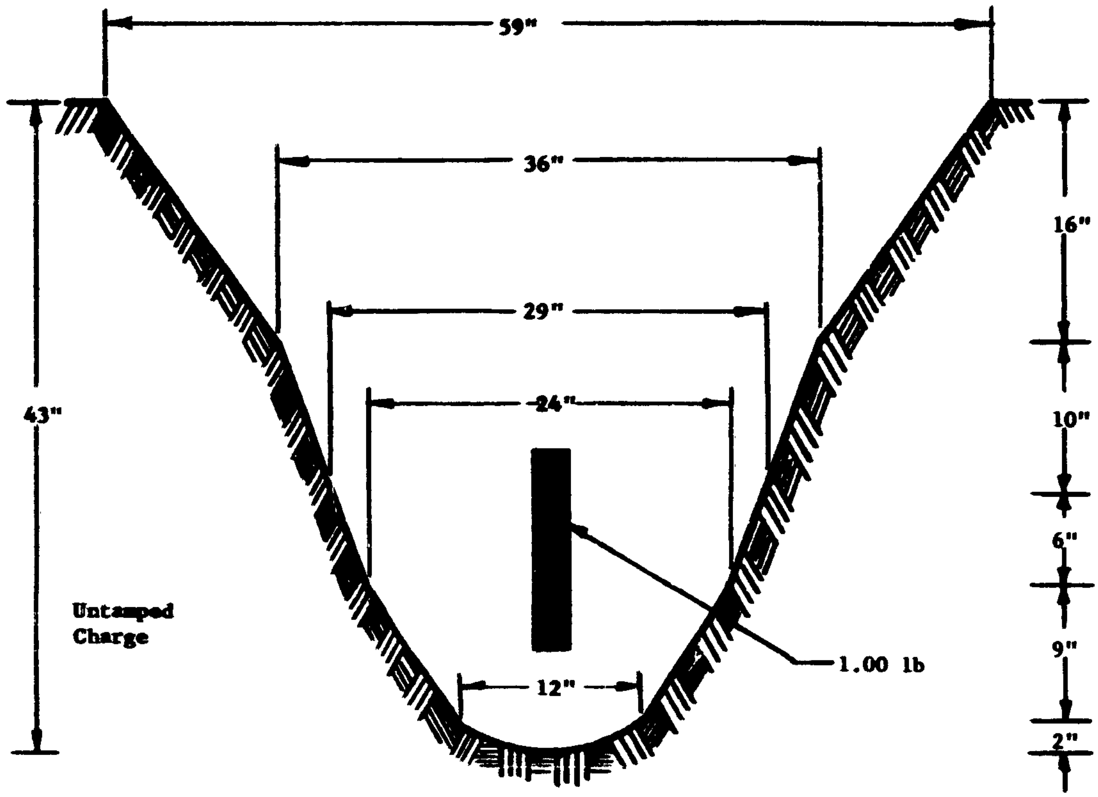

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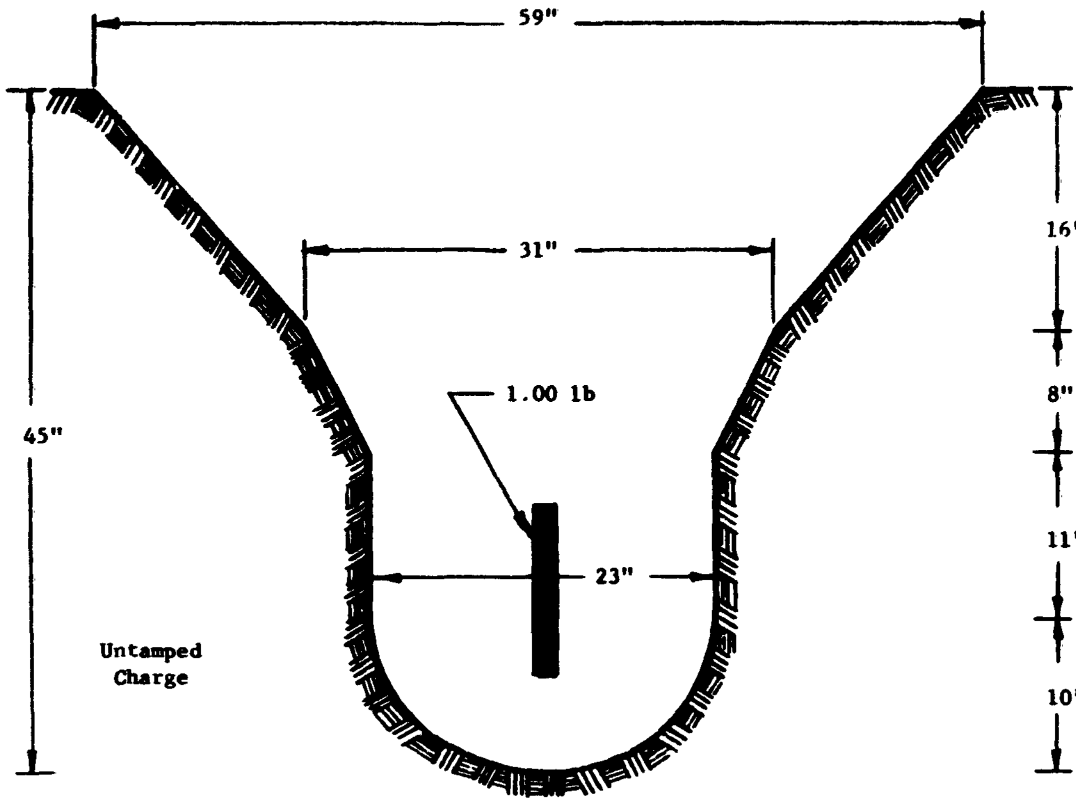

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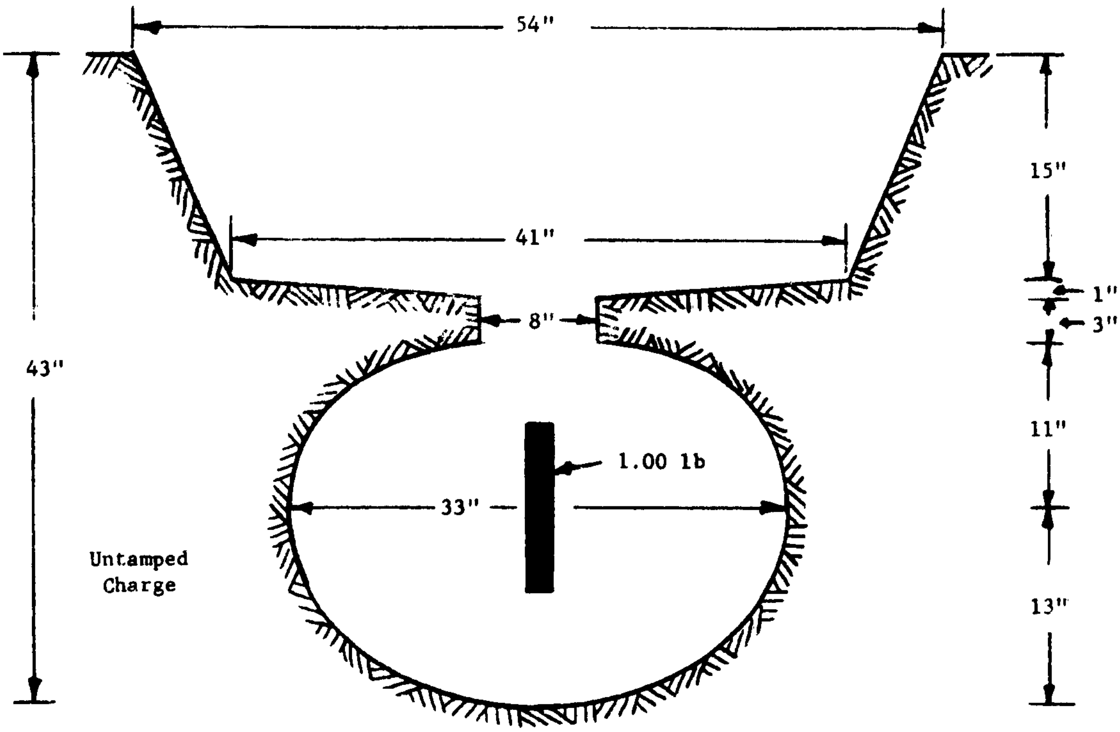

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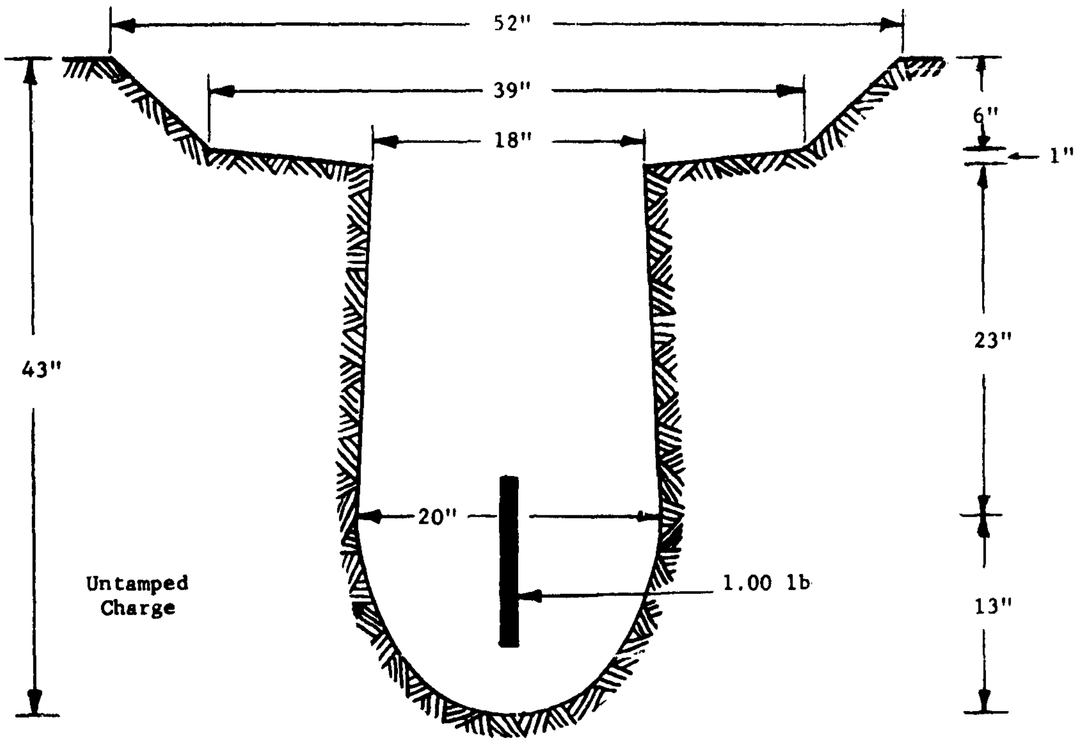

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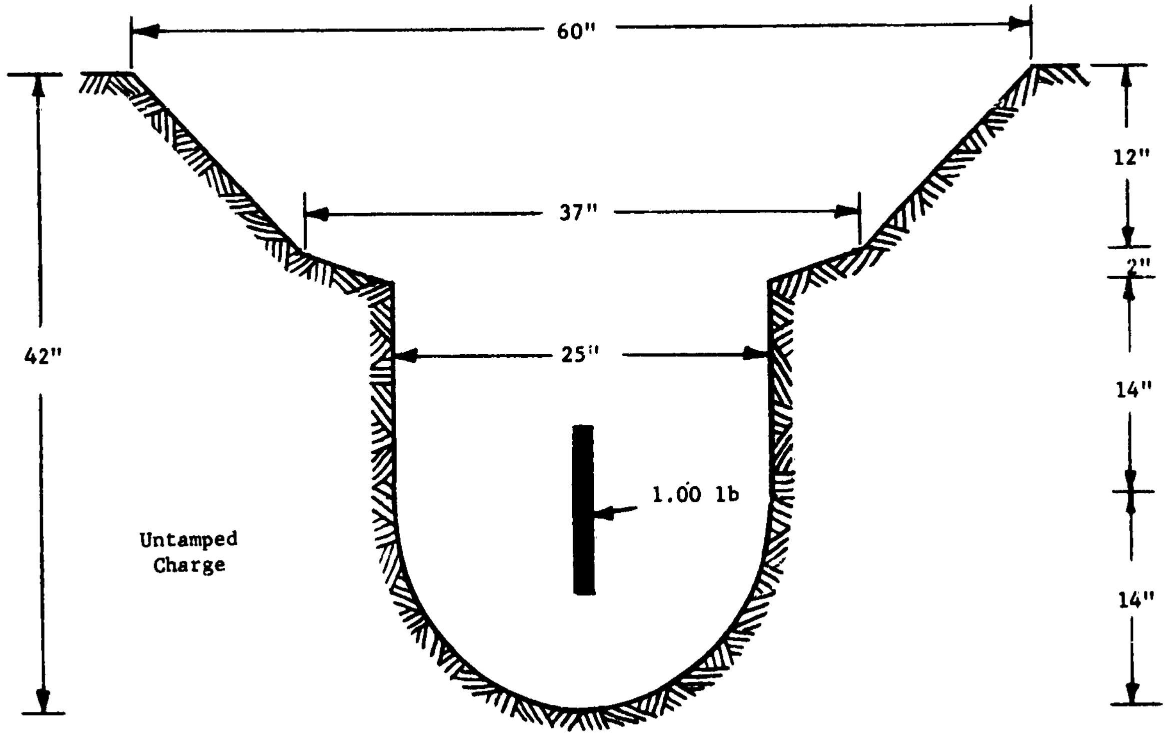

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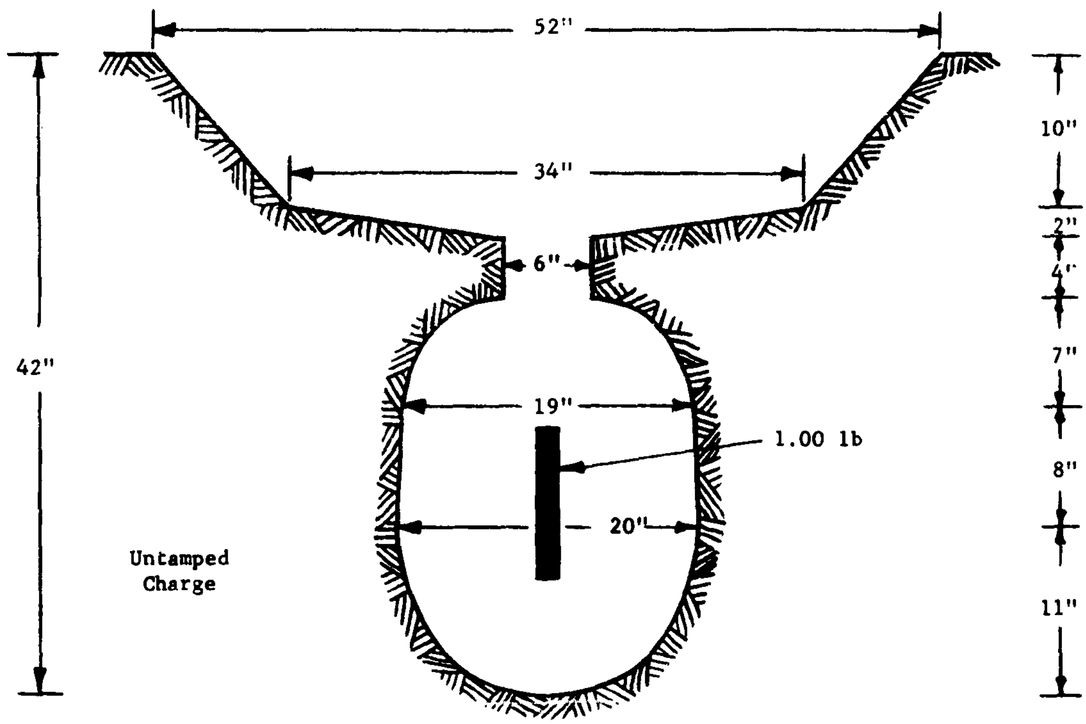

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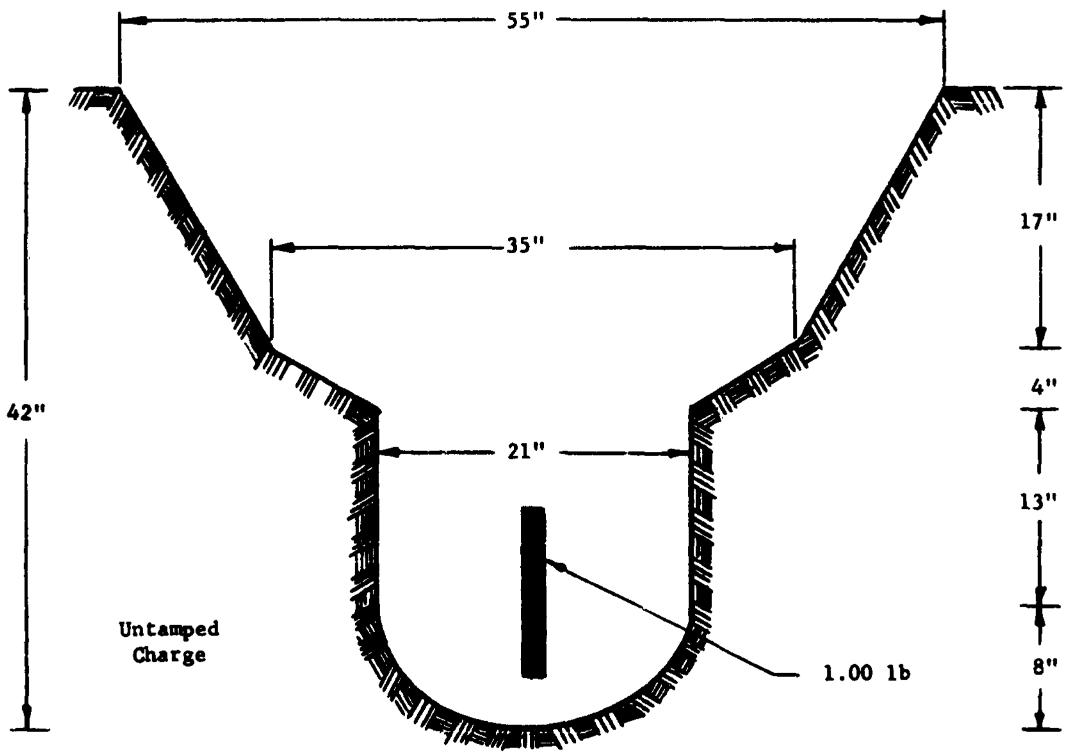

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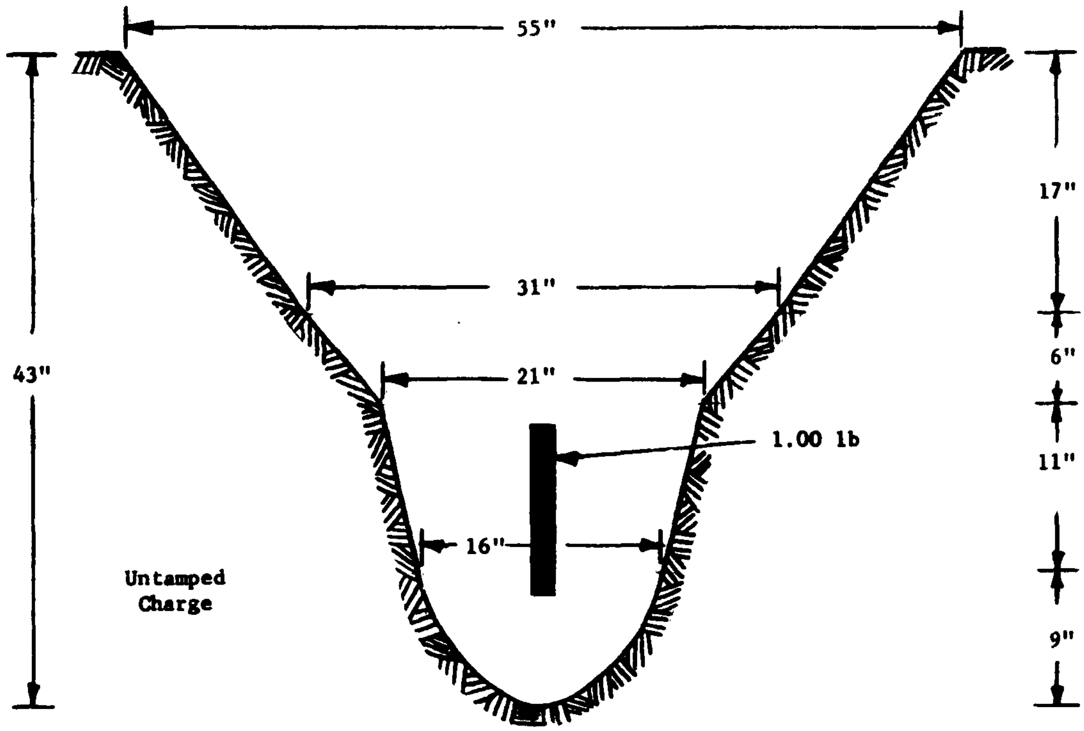

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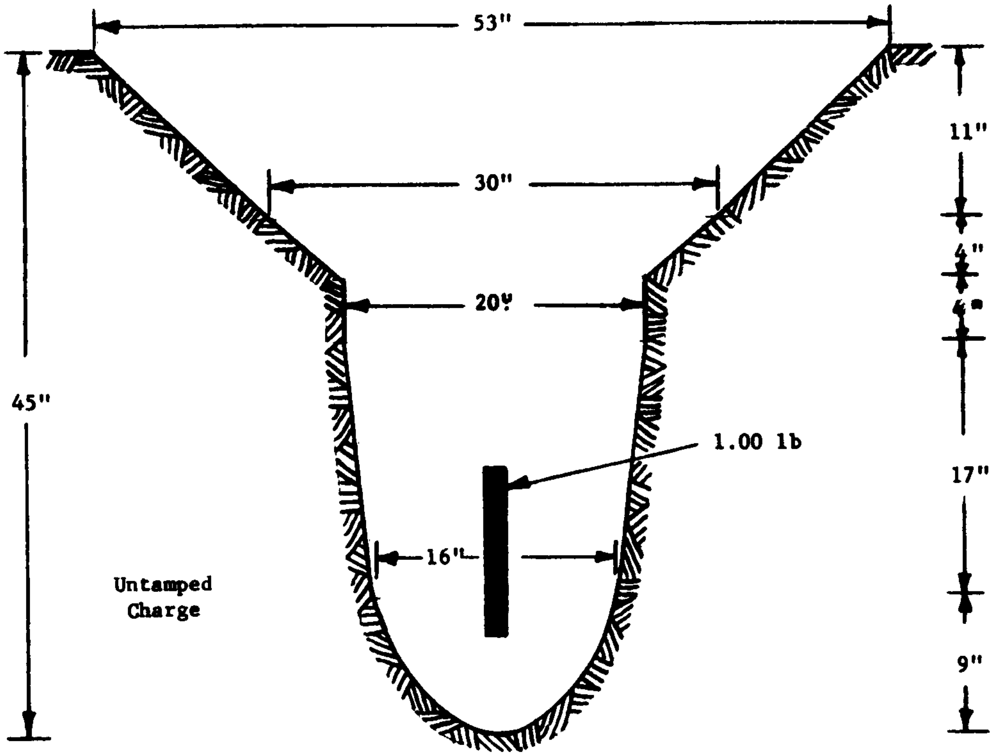

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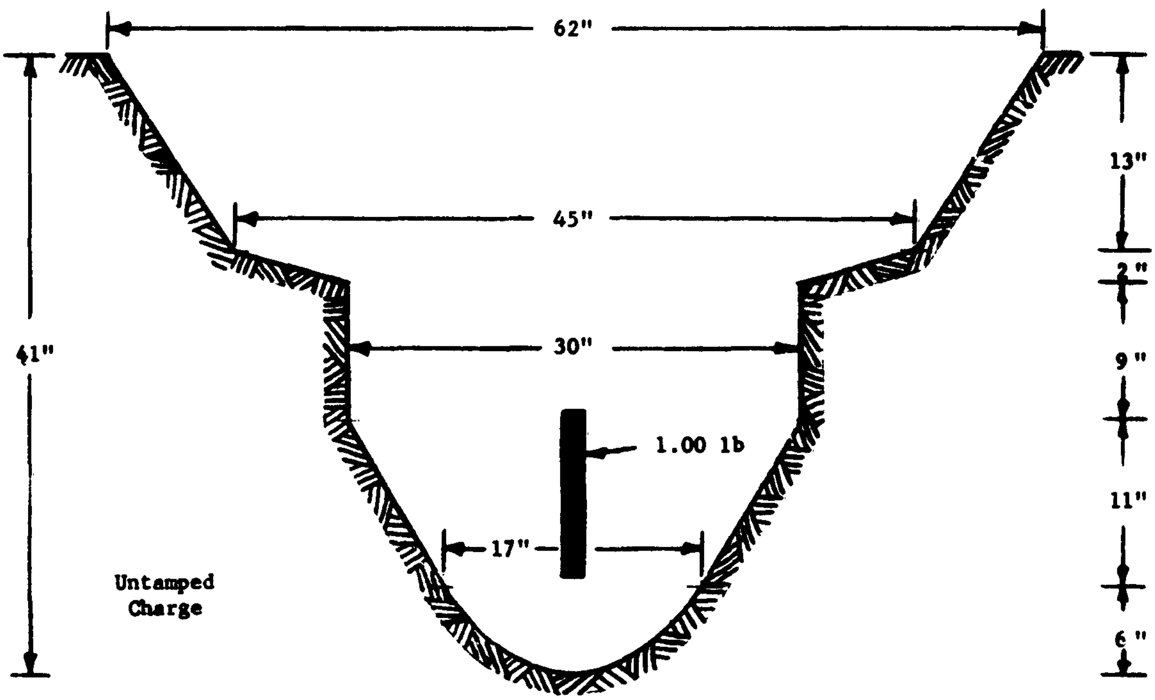

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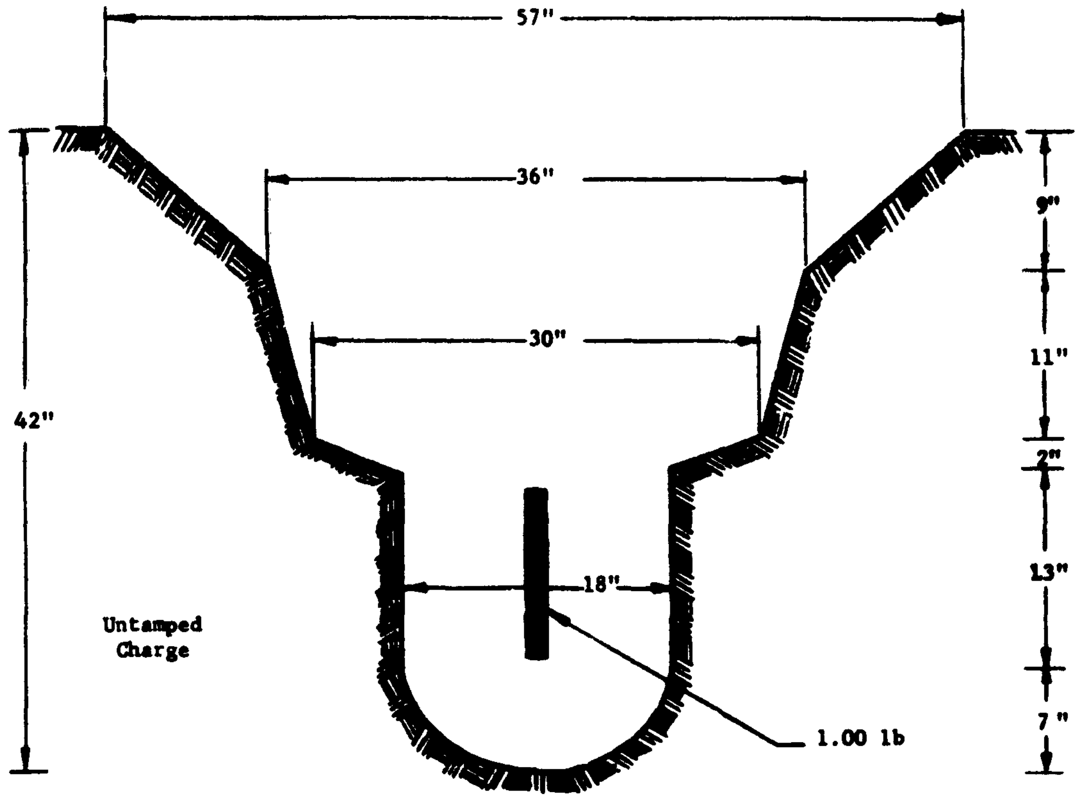

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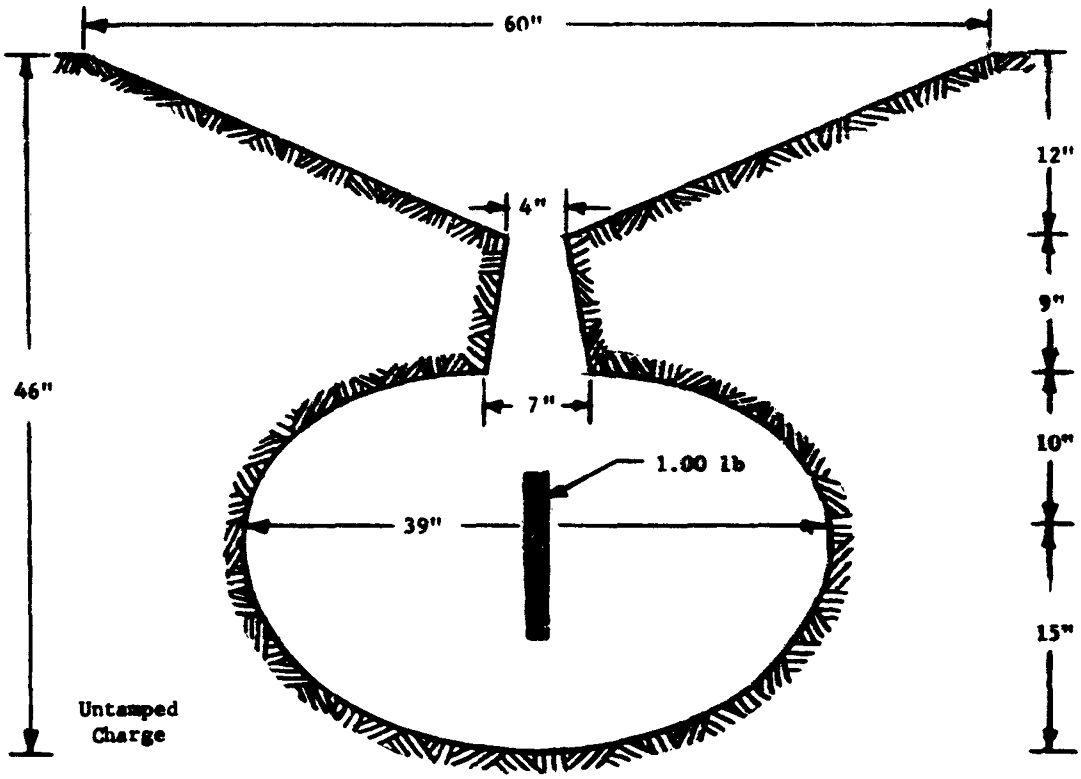

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